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EXPERIMENTAL BCAS PERFORMANCE RESULTS.(U)

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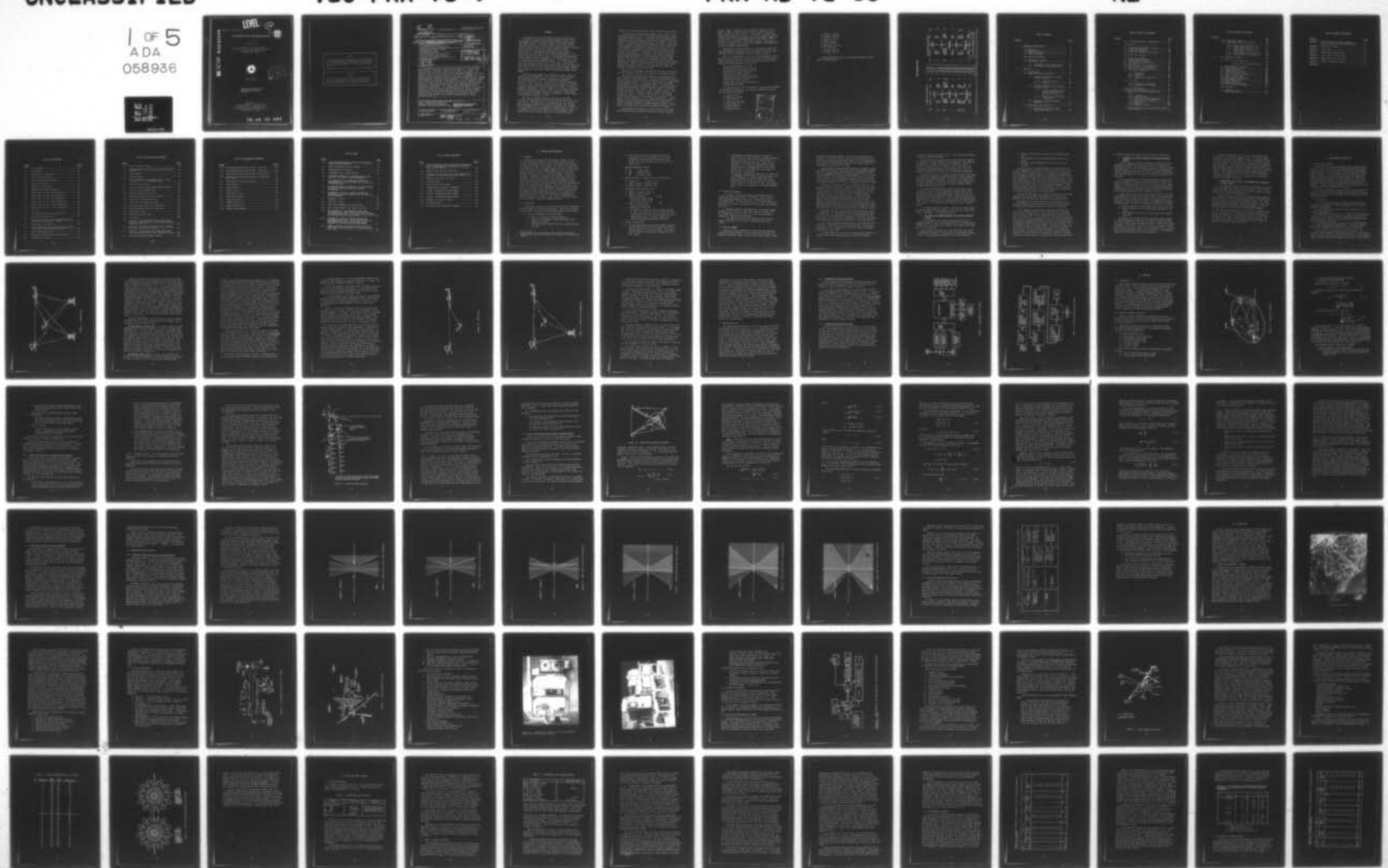

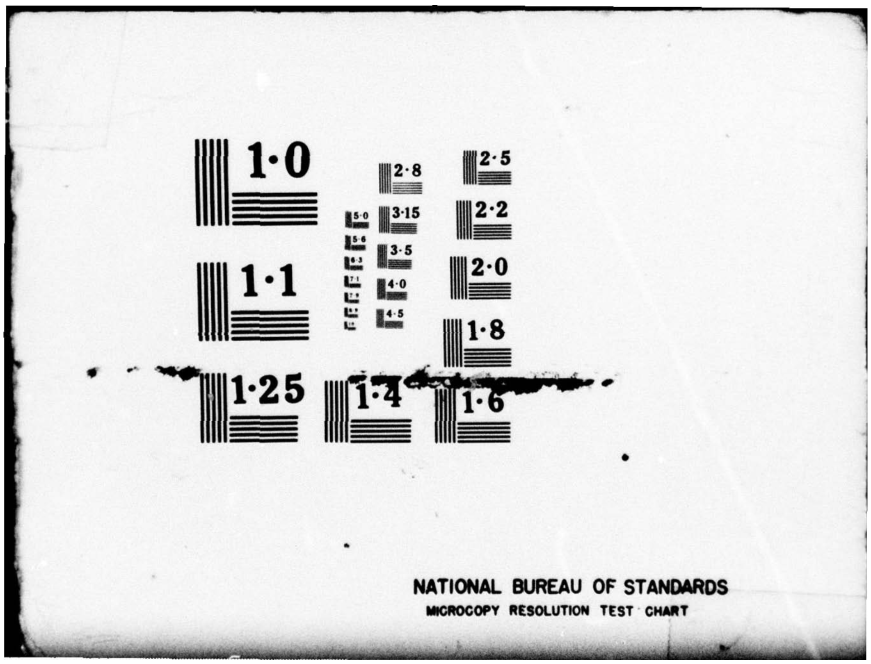
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REPORT NO. FAA-RD-78-53

EXPERIMENTAL BCAS PERFORMANCE RESULTS

Janis Vilcans
et al.

U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

JULY 1978
INTERIM REPORT

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16. Abstract

The results of the (Litchford) Beacon-based Collision Avoidance System concept feasibility evaluation are reported. Included are a description of the concept, analysis and flight test results. The system concept is based on the range and bearing measurements for detecting and resolving a threat. The experimental hardware, developed under Contract No. DOT-TSC-1103, Task 1-8, did not implement the automatic radar selection and lock-on mode and the capability to compute target range and bearing in real time which the concept requires. These enhancements are currently being implemented. All three generic modes of the BCAS were evaluated. These are: the passive (listen-in), the active (interrogate by on-board transmitter), and the combined (active-passive). Also, reported are results of the comprehensive in-house study effort conducted on the azimuth signal requirements and on single-site feasibility. It is concluded that the BCAS is a technically feasible concept and that the passive mode with an azimuth reference signal would be more accurate and less troublesome than other BCAS alternatives. For each operating mode there are geometries in which system performance fails or is degraded to some degree. System reliability may therefore require the implementation of various operating modes.

17. Key Words Beacon-based Collision Avoidance System, Single-Site CAS w/without Az Reference, Multi-Site CAS w/without Az Reference, Passive/Active/Semi-Active CAS	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

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PREFACE

The objective of the work reported in this interim report is to summarize measured and derived performance values of the experimental Beacon Collision Avoidance System (BCAS) hardware and software design. This BCAS concept is one of the several design options available, and it was conceived by George Litchford, who was awarded a sole source contract (Contract Number DOT-TSC-1103) to implement an experimental system function representative of the BCAS airborne and ground equipment. This effort comprises the initial step of the FAA/SRDS-250 Separation Assurance Branch toward development of the BCAS concept as a part of a national collision avoidance system. It is envisioned that the selection will be made by the FAA from one of the various BCAS design options and that the selected design will be compatible with the Air Traffic Control Radar Beacon System (ATCRBS) improvement program and the Discrete Address Beacon System (DABS) development.

The analysis and flight test evaluation program, under the sponsorship of FAA/SRDS-250, was carried out by TSC and NAFEC. The experimental BCAS equipment, developed and debugged by Litchford Electronics, Inc., was turned over to the Government on October 14, 1976. Extensive flight testing followed at the NAFEC test area acquiring technical performance data under a variety of parametric conditions. The test flights included flight encounters between two BCAS-equipped FAA aircraft, and also flights against a fixed target and against targets of opportunity. Flight tests were completed on December 17, 1976.

This report includes evaluation data for all hardware delivered in compliance with the contract DOT-TSC-1103, tasks 1 to 8 inclusive. After March 1977, the responsibility for the hardware development contract was transferred to NAFEC and, in addition, the contract was also augmented by adding tasks 9, 10 and 11 to implement the better main beam lock and the automatic radar selection and radar lock-on capability. The evaluation test

results of the added three tasks are not included in this report.

A TSC in-house design analysis effort was to study various BCAS design alternatives for the azimuth reference signal requirement and to perform studies on the BCAS critical characteristics. Performance trade-offs among various design combinations are reported. Critical design considerations, for example, synchronous garble, possible configuration for generating false targets, and an assessment of the potential interference with BCAS for the Joint Tactical Information Distribution System (JTIDS) are also covered in this report. In addition, under separate TSC memoranda the following results of analysis and tests are reported. Report number FAA-ARD-78-2, "Airborne Antenna Diversity Study" provides conclusions arrived at in analyzing airborne antenna diversity requirement for general aviation aircraft; Report number FAA-RD-78-34, "BACS Alternative Concepts for Determining Target Positions" provides in-depth design trade-offs for range and bearing calculations in the static case.

Analysis for the dynamic case and the covariance error analysis are in progress now and to be reported in subsequent reports.

The following individuals and agencies are acknowledged for their support to the BCAS program. Particular recognition goes to David R. Israel, former FAA Associate Administrator for Engineering and Development, for his vision and support of this program during initial design and development phases. Continuous support was provided by Martin T. Pozesky, ARD-200, Thomas M. Johnston, AEM-200, Richard F. Bock, ARD-251, John L Brennan, ARD-251, Owen E. McIntire, ARD-251, Richard L. Bowers, ARD-251, and Peter V. Hwoschinsky, AEM-20. Initially, the feasibility of the BCAS concept was assessed by an FAA created ad hoc committee. To the members of this committee a special appreciation goes to James J. Bagnall, Institute for Defense Analyses, Paul R. Drouilhet, Lincoln Laboratory, Donald A. Jenkins, ARD-241, Edmund J. Koenke, AEM-20, and Micheal Perie, ARD 102, the Committee Chairman.

The following TSC personnel are being recognized for their contributions during all phases of the BCAS concept evaluation

effort: James P. Andersen, TSC-50, Joseph M. Gutwein, TSC-531, Robert M. Hubbard, NAFEC (formerly TSC-433) and Wilfred Brown, MITRE, Bedford (formerly TSC-411). The efforts of Kentron International are appreciated particularly those of Michael D.Menn and Andrew Tobish. An acknowledgement goes to the efforts of the contractor for building an experimental system, in particular to J. Cole, R. Straub, and R. Galletta of MEGADATA. The flight test plan was designed by HH Aerospace.

Approximately 100 flights and over 200 hours of flight time were accomplished through the efforts of many different National Aviation Facilities Experimental Center (NAFEC) personnel.

While it is impractical to list all, acknowledgement is given herein to the following who supported the Systems and Equipment Engineering Branch, ANA-140 and the Transportation System Center (TSC) in the accomplishment of the project.

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Systems Test Branch, ANA-110
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The contributions of the individuals in these groups at NAFEC are gratefully acknowledged. Due special recognition, however, are the following personnel.

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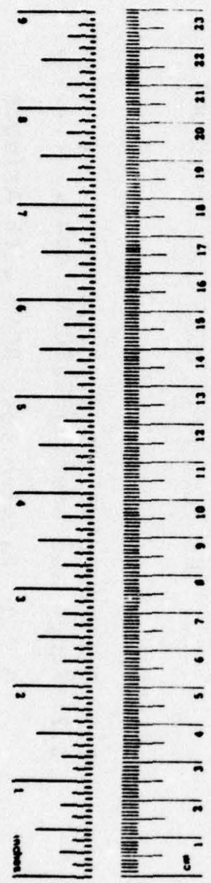
Special appreciation goes to the technical editor for this report, Kathleen Morely.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

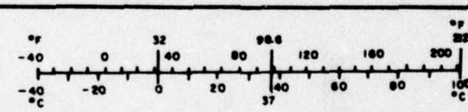


TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

1. SUMMARY AND CONCLUSIONS

1.1 GENERAL

Reported are analyses and flight test results of an air-derived collision avoidance system concept feasibility study. A possible application of the system is to assure safe separation of aircraft in flight. The concept utilizes the Air Traffic Control Radar Beacon System (ATCRBS) signals in space: ground interrogation signals and intercepted identity and altitude reply messages that they ellicit. From these signals, aircraft surveillance information is obtained and the threat possibility is evaluated. Vertical and possibly horizontal maneuvers may be provided from the Time-of-Arrival (TOA), Differential Azimuth (DAZ), and Own Azimuth (OAZ) measurements from which the range and bearing to an aircraft are computed. Only two experimental systems were evaluated; these represented one of the several design options, but lacked an essential part of the BCAS final design, the automatic ground radar selection and lock-on capability.[1] Another deviation from the final design was in computing the range and bearing to a target. These values were derived using off-line computers from the inflight test data.

1.2 CONCLUSIONS

An extensive analytical effort was carried out in conjunction with the flight test data analysis effort. The conclusion based on the results of those analyses and measurements are as follows:

1. Overall Assessment of the BCAS Concept.
   a. BCAS in a technically feasible concept;
   b. There is no perceptable interference effect upon ATCRBS surveillance;
   c. BCAS measurements compare well with ground precision tracking.

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[1] NAFEC reports that the automatic radar selection and lock-on capability has been verified under the contract No. DOT-TSC-1103, Task 11.

d. Each design alternative analyzed has some bad configurations to be recognized by the system designers to avoid excessive errors and false tracks; this includes the single-site system concept as well.

2. Measured Parameter Accuracy.

a. TOA .15 μsec (rms)
b. DAZ .3 degress (rms)
c. OAZ .25 degrees (rms)

3. Derived Parameter Accuracy for Good Configurations.

a. Bearing (θ) .3 degrees (rms)
b. Range to Target 300 feet (rms)
c. Range to Radar 3000 feet (rms)

4. Experimental BCAS Characteristics.

a. Number of Targets Tracked 9
b. Number of Radars Locked 3
c. Range to SSR (max.) 100 nmi
SLS Receiver minus 90dbm
MB Receiver minus 65 dbm
d. Range to Target (max.) 8 nmi
Receiver minus 85 dbm
e. Probability of Detection -
All targets within the coverage region detected by BCAS. For some aircraft, both ARTS and BCAS formed multiple tracks, but not necessarily at the same azimuth angle. No missed targets were observed comparing BCAS against ARTS data.

5. Design Considerations.

a. The proposed design option without radar azimuth reference signals-may not provide sufficient target bearing accuracy to give good tracks. Two aircraft and two radars are the minimum configuration for this system.

b. A design option requiring azimuth references signals from all radars requires a minimum configuration of two radars and one intruder aircraft to determine the intruder position. Under some circumstances, this system may produce false tracks which can not be distinguished from a true track, except that in time ground radars will appear to move relative to each other.

c. A mixed mode configuration, when only one radar site is equipped with the azimuth reference signal, provides a measurement accuracy better than the no azimuth reference system, but would not generate false targets as in the previous case. Two targets and two radars are required for a minimum configuration.

1.3 FLIGHT TEST SUMMARY

In a total of fifty-four flights, two-hundred hours of flight test data were recorded at the NAFEC. Some collected data required additional testing, but in general most data were satisfactory. The only tentative area is the evaluation of the threat logic where only qualitative conclusions can be made. These are:

1. Multiple targets which appeared in the Widened Azimuth Window were not verified by ARTS data taken at the same time. In the ARTS data, multiple targets for the same BCAS target appeared at a different azimuth angle.

2. The threat detection logic appeared to be biassed to reduce missed alarm; as a result, it generated some false tracks.

1.4 ANALYSIS SUMMARY

Analyses have been performed for the static case and algorithms have been developed to enable computation of range and bearing to potential threat aircraft and to ground radars, using

passive-mode BCAS measurements. Only the static solutions are presented. These are solutions based on the differential time of arrival (TOA), differential azimuth (DAZ) and, where appropriate, own azimuth (OAZ) measurements taken at one instant for the configuration as it exists at that time.

The algorithms compute range and bearing to intruder aircraft and radars on the basis of only the current measurements, making use of no a priori knowledge of either the positions of the aircraft or radars or of any previous measurements. For this reason, the accuracies of the computed positions are likely to be worse than those that would be obtained by dynamic tracking algorithms which would smooth out the effects of measurement errors over time.

The solutions obtained are the solutions that best fit the measurement data. Thus, their accuracy is the intrinsic accuracy to within which the relative positions of intruder aircraft and locked radars can be determined from the measurements made with the given accuracy at one point in time. Dynamic tracking algorithms, when they are developed, may be expected to have better overall performance because they will have available sequences of positions over a period of time and will be able to smooth out measurement errors by effectively averaging over time. The statistically computed accuracies should be suggestive of the accuracies that the tracking algorithms should be able to achieve.

Algorithms for fully passive BCAS were developed and tested in simulations. An algorithm for use in the mixed mode of operation using active interrogation and passive measurement for one locked radar is presented for completeness. The error sensitivity of the solution in this mode of operation has not been analyzed.

Three different modes of purely passive operation have been simulated. These assume all radars equipped with azimuth reference signals, none so equipped, and only one radar so equipped available at a given time.

It appears that when no radars are equipped with azimuth references, the target bearing cannot be derived sufficiently

accurately to give good target tracks. This conclusion should be verified by dynamic simulation.

When all radars are equipped with azimuth reference signals, the positions of single targets can be determined. The range of configurations in which the solution is excessively error-sensitive is smaller than for the other cases, but under some circumstances the measurements lead to ambiguities in that two distinct configurations can give rise to the same measurements.

When only one radar has azimuth reference signals, two target aircraft must be observed to make calculations of position based on passive measurements possible. The range of configurations in which the solution is excessively sensitive to measurement error is larger than when all radars have azimuth reference signals; mulitple solutions do not occur.

In the good configurations of radars and aircraft, target aircraft positions can be determined to within an RMS error of less than 300 feet, assuming measurement accuracies like those obtained by the experimental BCAS system. Radar positions can be determined much less accurately. Errors range from somewhat less than a mile to several miles in configurations with small differential azimuths. The system with two target aircraft is slightly better.

It is judged that either system - assuming all radars equipped with azimuth reference signals or only one radar within BCAS range so equipped - is technically feasible.

1. All radars are assumed equipped with azimuth reference signals.

In this situation, the range and bearing from BCAS of a single intruder aircraft can be determined if it is being tracked by BCAS using two or more ground radars. The range to each radar can also be calculated.

Both simulated and flight test data verify that this mode of operation is possible in all but a set of unfavorable configurations. The unfavorable configurations are the following:

a) BCAS in line with the two radars; both radars on one side.

b) The intruder aircraft between BCAS and either of the radars.

c) The BCAS aircraft between one of the radars and the intruder.

The width of the bad ranges depends on the characteristics of the configuration as a whole. In the worst part of each, the iterative solution algorithm fails to converge to any solution. Near the edges of the bad region, the configuration computed from the measurements is highly sensitive to measurement errors. This error sensitivity is intrinsic in that the configurations are such that large changes in the relative positions of the aircraft (and radars) cause small changes in the observed measurements. Then, inversely, small changes in the measurements, such as those arising from measurement noise, cause large changes in the configuration that can be deduced from the measurements.

Outside the bad ranges, the relative position of the intruder aircraft can be calculated with an RMS error in position of generally less than 300 feet, depending on the configuration.

The ranges to the radars can also be calculated, but the values obtained are quite sensitive to errors in the measurement of differential azimuth and may have errors of several miles

It is important to notice that, under some circumstances, two distinct configurations of radars and aircraft will produce the same set of values for all the measurements obtained by the BCAS. In such a case, it is theoretically impossible to determine from the set of static measurements obtained at one time which of the possible configurations actually gave rise to the measurements. The ambiguity can be resolved by making other measurements, e.g., an active measurement of target range. In addition, although the possibility of the false solution may persist for a period of time, so that a false track for the intruder may be established instead of the true one, the radar positions computed in conjunction with the false track will in time be seen to be inconsistent

in that the radars will appear to move relative to each other.

2. No radars are assumed equipped with azimuth reference signals.

In this situation, BCAS can determine the shape of the configuration of radars and aircraft if there are two radars and two target aircraft. The measurements contain no absolute azimuth reference signal. Hence, the orientation of the configuration cannot be determined directly, but only the bearing of each radar and aircraft relative to some arbitrary reference within the configuration.

It has been suggested that the BCAS-equipped aircraft might be able to compute its own position relative to the radars at a number of consecutive times. Then it could relate its own flight direction to the fixed direction of the line connecting the two radars and use that as the known reference direction in determining the bearing angles toward the intruder aircraft.

It was found in the course of the simulations that the range of configurations in which the computed results are intrinsically highly sensitive to measurement error is more extensive in this case than in the case where both radars are equipped with azimuth reference signals. The bad configurations include the following:

a) BCAS in line with the two radars; both radar on one side.
b) Either intruder aircraft between BCAS and either of the radars.
c) Both intruder aircraft in the same direction as viewed from BCAS.

In addition, the current heuristic algorithm used to obtain an initial approximation tends to fail when an intruder aircraft is in the direction directly opposite that of a radar, when viewed from BCAS, or when BCAS is directly between the intruder aircraft. The difficulty in these regions can be eliminated, since it arises from the algorithm used, and not from the nature of the dependence between the configuration and the measurements.

For those configurations in which the aircraft and radar positions can be reliably computed, (i.e., in the good ranges), the errors in range to the target aircraft are comparable to the errors obtained using radars that are all equipped with azimuth reference signals. The computed radar distances are considerably more accurate. However, the bearing angles computed relative to the line connecting the radars have errors on the order of several degrees. This suggests that the proposed scheme of operation with no azimuth reference signals at all may have difficulties. A definitive judgment must rest on an analysis of a tracking scheme in the dynamic situation.

3. Some radars, but not all, are equipped with azimuth reference signals.

It is assumed that the BCAS at any one time would be in range of only one radar with azimuth reference signals. Other radars would be available for locking and for tracking targets, but these would not have azimuth reference signals.

In such a situation, the problem of computing the configuration of radars and aircraft at any one instant is essentially the same as in the case of no azimuth reference signals. Two radars and two aircraft are required. The only difference is that, once the shape of the configuration has been determined, it can be properly oriented on the basis of the azimuth measurement.

The extent of the bad range for this case is identically the same as in the case of the system with no azimuth references, as is the error sensitivity of the computed ranges to the intruder aircraft and the radars. The bearing errors to the radars and the aircraft are smaller than those achieved when no radars are equipped with azimuth reference signals.

2. BCAS CONCEPT DESCRIPTION

2.1 DEFINITION OF CONCEPT

The Beacon-based Collision Avoidance System (BCAS) concept (which in a few cases differs from the experimental BCAS design) is based on the use of Air Traffic Radar Beacon System (ATCRBS) signals in space. By receiving both interrogations from multiple ground sites and their elicited target replies and processing them in an on-board computer, the BCAS detects all targets in a coverage volume, computes their range and bearing in real time, identifies potential threats, and determines suitable evasive maneuvers. Both the indicated maneuver and the relative position of other aircraft are displayed to the pilot.

The basic differences in concept between BCAS and other CAS systems are that BCAS derives and uses the bearing to the threat, and that BCAS explicitly uses ATCRBS signals without interference to ATC operations.

In particular,

1) The threat determination and the selection of evasive maneuvers are performed in flight, independently of ground surveillance and computers.

2) Both vertical and horizontal evasive maneuvers may be selected, as appropriate.

3) BCAS derives the bearing to the threat by multilateration techniques, using signals from several ground sites received on an omni antenna, instead of using scanning beam antennas or RF phase measurement techniques.

4) BCAS provides protection against all aircraft equipped with standard ATCRBS Mode C transponders. It does not require any special equipment on the threat aircraft for operation.

BCAS has two operating modes--passive and active. The principal operating mode is the BCAS passive mode. In the passive mode, the BCAS monitors ground radar interrogations and transponder replies without emitting interrogations of its own. (See Figure 2-1)

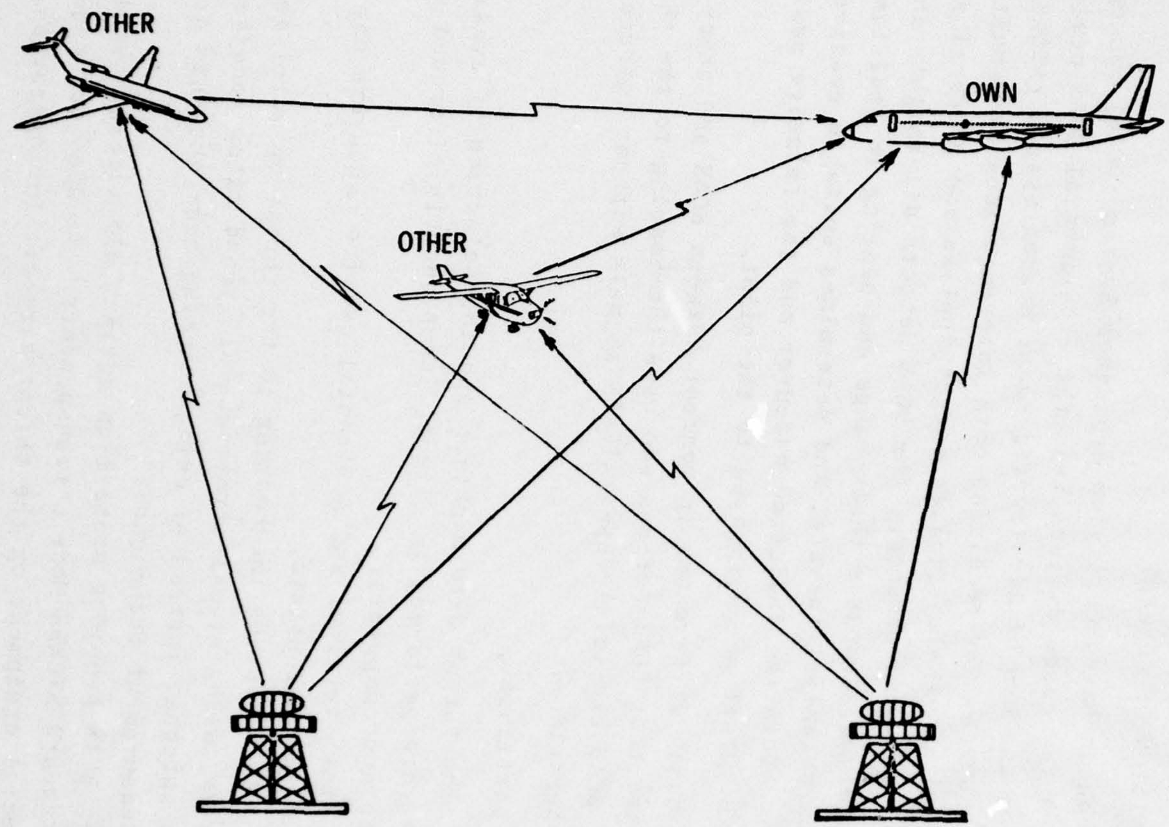


FIGURE 2-1. PASSIVE BCAS

From the sequences of interrogations received by the BCAS aircraft while in the successive main beams of the ground interrogator, the BCAS can determine characteristics of the radar which allow it to "lock on" the radar., i.e., to calculate the relative angular position of its antenna and to predict the time of occurrence and the mode of its interrogations. Basic properties that characterize each radar are interrogation frequency, interrogation mode interlace, and rotation period. Each radar has a fixed interrogation sequence, generally distinct from those of all other radars in its area. The interrogation sequence may be either a fixed pulse repetition period (PRP) sequence, in which all interrogations are uniformly spaced, or a staggered PRP sequence, in which a sequence of up to 8 different PRP's repeats periodically. Each radar also has a fixed interrogation mode interlace pattern, typically ACAC or AACAAC (A identity, C altitude) and a constant antenna rotation rate. All interrogator antennas rotate clockwise, i.e., W to N to E.

Two basic measurements, the DAZ and TOA are made in the passive mode and serve to relate the position of the BCAS, the interrogator, and the target aircraft.

<u>The Differential Azimuth (DAZ)</u> is the angle between the BCAS equipped aircraft and the aircraft of interest as measured from the ground site. It is the angle between the interrogator beam when pointing at the BCAS and when pointing at the other aircraft. It is computed by dividing the interval between the time that the interrogator antenna points at the BCAS and the time it points at the other aircraft by the rotation period of the antenna. The time that the antenna points at the BCAS is taken to be at the middle of the burst of main beam interrogations received. The time that it points at the other aircraft is taken to be at the middle of the group of replies elicited by the interrogator and received by the BCAS "listening in".

<u>The Time of Arrival (TOA)</u> is a delay in time between the directly received interrogation at the BCAS equipped aircraft and the time of receipt of the intercepted reply from the other

aircraft to the same ground radar interrogation. It is a measure of the difference between the straight line distance from the SSR to the BCAS and the sum of the distances from the SSR to the other aircraft and from the other aircraft to the BCAS. If both the BCAS and the other aircraft are simultaneously in the main beam of the interrogator, the TOA can be measured directly as the interval between the receipt of the P_3 pulse from the interrogator and the transponder reply from the other aircraft, (reduced by 3 microseconds to compensate for the transponder delay). When only the other aircraft is in the main beam of the interrogator, the TOA is determined as the interval between the calculated time the P_3 pulse would have been received and the receipt of the transponder reply, corrected by a 3 microsecond transponder delay. The time at which the P_3 pulse would have been received may be calculated in two ways. The BCAS may receive the P_1 and P_2 pulses radiated outside the main beam for side lobe suppression and add to the time of receipt of the P_1 pulse the P_1 - P_3 interval appropriate to the interrogation mode used. Alternatively, the BCAS may calculate all P_3 times on the basis of the main beam interrogation times and the measured interrogation patterns and pulse repetition periods (PRP). Both approaches have been implemented in versions of the experimental BCAS system.

If the ground radar site is equipped to generate an azimuth reference signal, then the BCAS can also determine its Own Azimuth (OAZ) with respect to the radar by comparing the interval between the azimuth signal when the antenna is pointed in a known direction and the time of main beam center passage past the own aircraft with the antenna rotation period. In general, the BCAS and the threat aircraft must both be in the coverage region of at least two of the same ground radars if the calculation of the other aircraft's position with respect to the BCAS is to be possible on the basis of the passive mode measurements.

Outside of such ground radar coverage, the BCAS operates in the active mode, emitting ATCRBS-compatible interrogations with

an on-board transmitter. The TOA measurements obtained from the active interrogations are directly proportional to range. The target altitude is obtained from mode C replies.

In the total absence of the ground radar coverage, e.g., over the ocean, active mode BCAS (See Figure 2-2) has available only range and relative altitude information from which only vertical threat avoidance maneuvers can be determined.

In a single ground radar coverage (See Figure 2-3) with known azimuth, the passive and active measurements may be combined and are sufficient to calculate the bearings to the threat, so that horizontal threat avoidance maneuvers can be selected where appropriate.

There is a variety of conditions under which the positions of threat aircraft relative to the BCAS can be computed from the BCAS measurements. In general, if own azimuth (OAZ) to two ground radars is known, then the range and bearing to a single target can be calculated from the passive mode BCAS measurements. The calculations also yield values for the distances to the radars, though these tend to be quite sensitive to measurement errors.

If OAZ relative to both ground radars is not known, then no solution based only on passive mode measurements is possible for a single target aircraft. In the presence of two targets, it is possible to compute the range to each target and each radar, and the bearings of the radar and the targets relative to each other. i.e., one can calculate the shape of the configuration of radars and aircraft, but not its orientation in space. If OAZ to one radar is known, the orientation of the configuration is determined. Otherwise, one can in principle compute the configuration at several successive instants of time, separated by an interval during which the BCAS aircraft has moved, and use the known direction of motion to orient the configuration of aircraft and radars. A solution requiring no OAZ signals from the ground sites is the most desirable one, in that it permits BCAS operation without requiring any modification of ATCRBS ground sites.

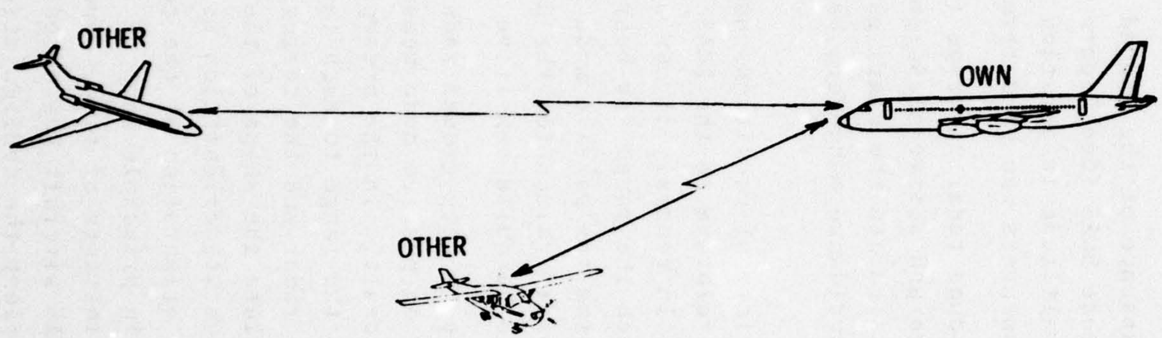


FIGURE 2-2. ACTIVE BCAS

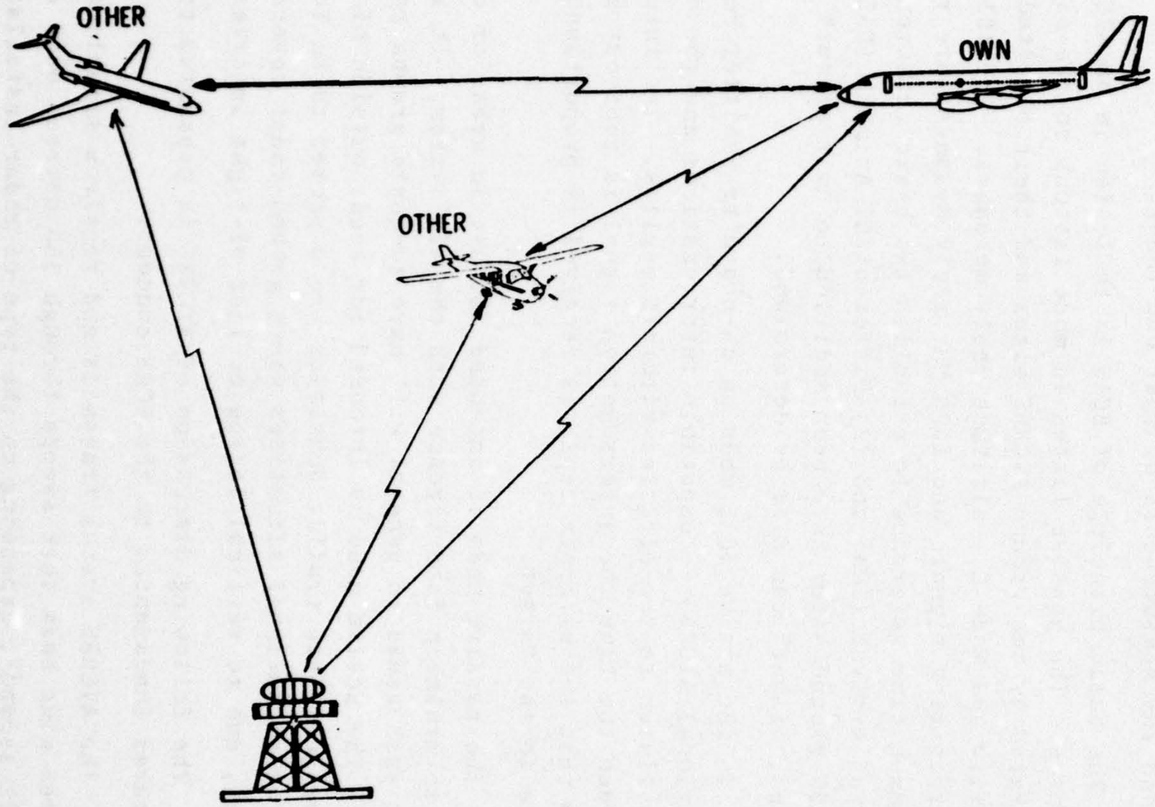


FIGURE 2-3. PASSIVE/ACTIVE COMBINATION

Once the distance and direction from the BCAS of a radar has been established, then the position of any number of potential threat aircraft relative to the BCAS can be determined from the DAZ and TOA measurements of that one radar.

The basic principle of BCAS is to listen in on ATCRBS signals in space. The passive listen-in mode listens to the signals generated by the ground ATCRBS sites and their elicited Mode A - identity and Mode C - altitude reply messages. The 1030 MHz interrogating signals and 1090 MHz reply messages are received in a common time reference to establish two basic measurements: (1) Time-of-Arrival (TOA) and (2) Differential Azimuth (DAZ). If ATCRBS ground sites have been modified to emit azimuth reference pulses, Azimuth can also be determined.

In the active BCAS mode an on-board transmitter generates additional ATCRBS - compatible interrogations and the system can then listen to the elicited aircraft replies. The interval between the time the interrogation signal is sent out and the time that the aircraft reply is received is proportional to the range to the target.

The passive mode is intended for use in areas of dense traffic to minimize interference with the ATC system. It is assumed that such areas in general will have adequate ground radar coverage. The active mode is intended for areas outside of radar coverage (where traffic densities are expected to be low), as well as for exceptional situations where ground radar coverage fails (e.g., due to vertical lobing or line-of-sight interference).

The following discussion of ATCRBS is presented to bring out features fundamental to the BCAS concept.

The ATCRBS system transmits and receives signals on a four-degree wide beam that sweeps through 360 degrees once every four or 12 seconds, depending on the type of radar installation. Transponder interrogation pulses are transmitted on a frequency of 1030 MHz, and the transponder replies are transmitted on a frequency of 1090 MHz. The interrogation pulses are typically

transmitted once every 2.5 milliseconds, so that an aircraft transponder is interrogated about 20 times as the beam sweeps over it. The interrogation pulses consist of two major pulses that are generally separated by 8 or 21 microseconds, depending on the type of transponder interrogation being employed. The 8-microsecond spacing (Mode 3/A) elicits an identity-coded message from the transponder, while the 21-microsecond spacing (Mode C) elicits an altitude-coded message. Other interrogation types, characterized by different pulse spacing, are defined. The BCAS is not required to reply to these or to recognize replies to them from other aircraft. However, the BCAS will be able to identify their presence in the mode interlace pattern in order to determine the radar stagger pattern, so as to be able to lock to a radar using other modes in addition to modes 3/A and C. All transponder replies are delayed by 3 microseconds, and the subsequent reply consists of two framing pulses separated by 20.3 microseconds, with up to 12 identity or altitude code pulses between the framing pulses.

2.2 EXPERIMENTAL BCAS

The experimental BCAS differs in only a few respects from the BCAS concept described in Section 2.1. It is based on the concept of listening in on the ATCRBS ground interrogations and their elicited replies within ground radar coverage areas, and of generating ATCRBS-compatible interrogations with an on-board transmitter in those areas where ground radar coverage is poor or nonexistent. Experimental BCAS does not require any a priori knowledge of the environment, the radar sites, or target equippage, and it provides protection only if the threat aircraft is equipped with an ATCRBS transponder replying with both altitude and identity codes (Mode C). At the time for the tests reported here, the system required operator intervension to achieve radar lock, and the computations of the target range and bearing were carried out on the ground from data recorded in flight.

2.2.1 Experimental BCAS System Design

A block diagram of the experimental system designed to test operation in both the passive and the active mode is shown in Figure 2-4, and its functional diagram in Figure 2-5.

The system was locked manually to ground radars with both fixed and staggered PRP's and measure TOA's and DAZ's. A number of SSR's were modified to emit azimuth reference signals so that the system could also determine OAZ. For the purpose of this experiment only the azimuth pulses were radiated at 1030 MHz on the omni and main beam antennas of the interrogators 2 microseconds after the P_3 pulse. The experimental system (See Figure 2-4) included a magnetic tape drive for recording data for post-flight analysis, and a color alphanumeric CRT display and a teletype for real-time performance monitoring. Range and bearing calculations for threat aircraft were performed after the flight from the recorded data. The system included an active interrogator to allow simple active mode operation in addition to the passive mode operation, and combination of active and passive modes.

2.2.2 Experimental BCAS Modifications

Two major improvements are being added to the experimental system: (1) automatic radar selection and lock-on and (2) maintaining radar lock by synchronizing the BCAS internal clock with the main beam interrogations, rather than by continuously monitoring SLS pulses. Both modifications have already been tested successfully according to information from NAFEC. Additional BCAS improvements are being sought; these will include in-flight computation of target range and bearing for estimating flight trajectories and the resultant capability to determine and command horizontal evasive maneuvers.

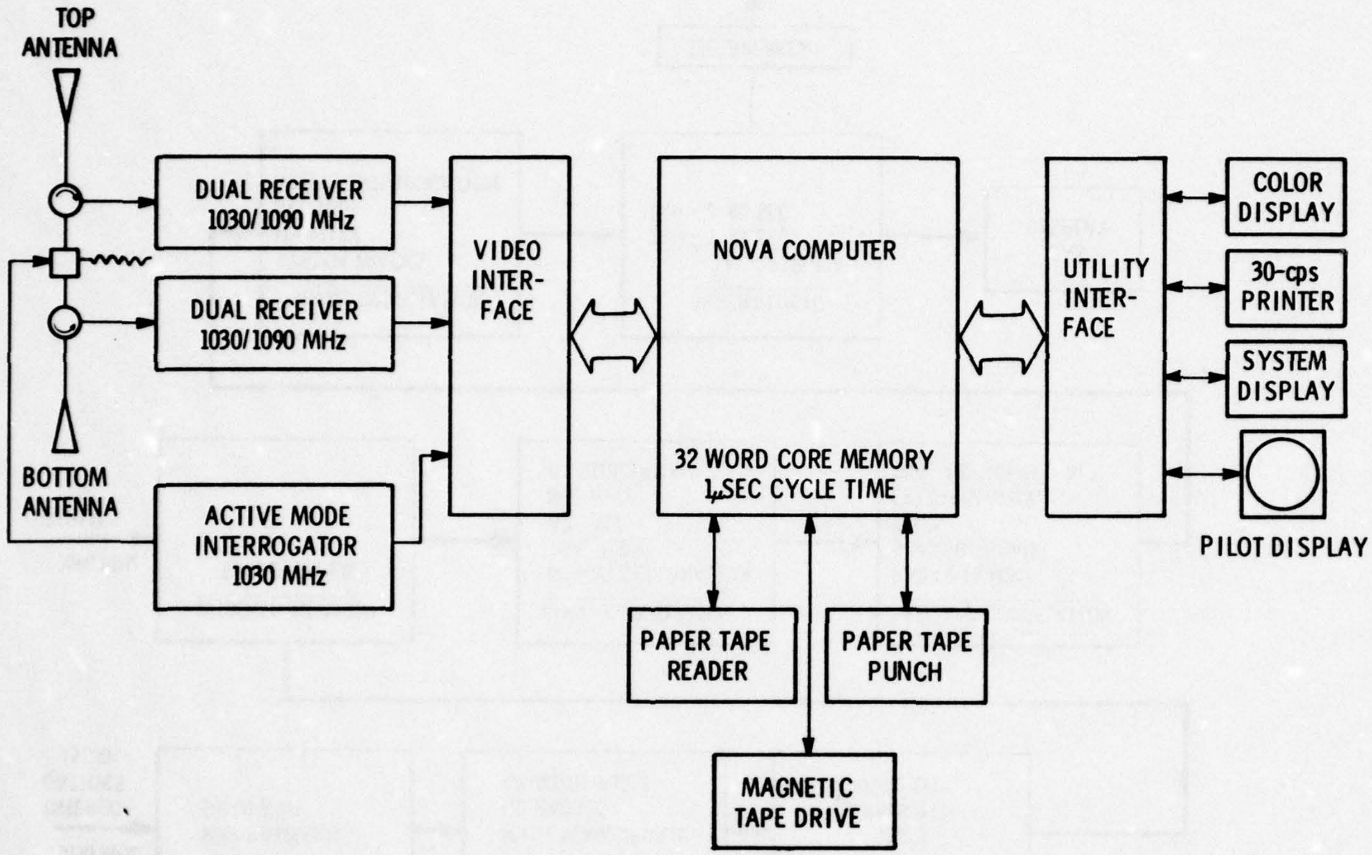


FIGURE 2-4. EXPERIMENTAL BCAS SYSTEM

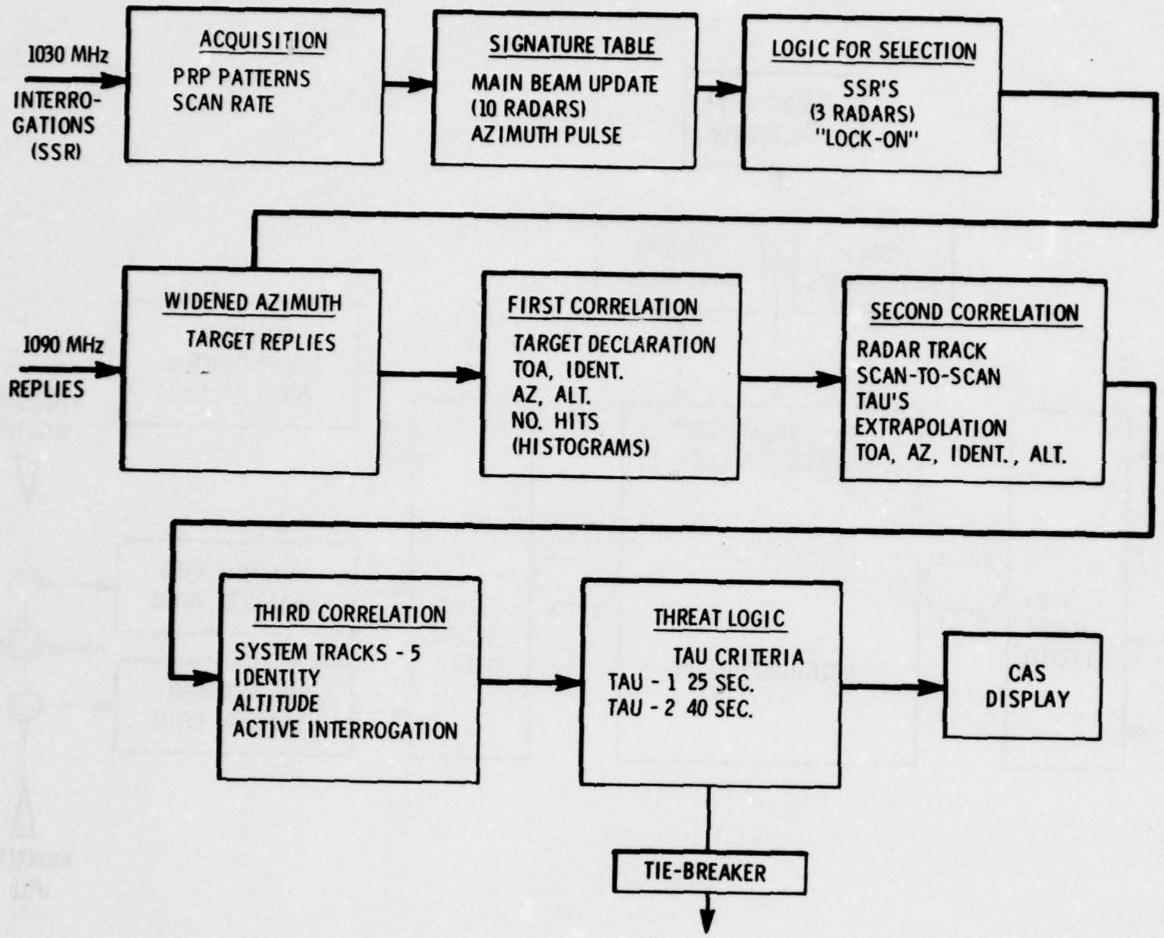


FIGURE 2-5. BCAS FUNCTIONAL BLOCK DIAGRAM

3. ANALYSIS

3.1 INTRODUCTION

This section summarizes analyses of the BCAS concept feasibility assessment study. Only a limited development of the equations is given in the report; for more details one should refer to the following references: (1) Report number FAA-RD-78-34, "BCAS Alternative Concepts for Determining Target Positions" discusses trade-offs of alternative designs, and (2) Report number FAA-RD-78-2, "BCAS Airborne Antenna Diversity Study" reports flight test results and conclusions on the BCAS link reliability measurements for the general aviation aircraft for both top and bottom mounted antennas. Interference analysis details not covered adequately in this report are available in the Technical Memorandum No. 1, "Tests and Analysis of JTIDS Interference with BCAS."

3.2 RANGE AND BEARING CALCULATION

Figure 3-1 shows the geometric relationship between the range and bearing of a target aircraft and the quantities measured by BCAS by monitoring the interrogations and elicited replies of a single SSR site.

The following equations describe the relationships among the various parameters analytically. The subscript i designates one SSR out of the available set:

The measured quantities are:

β_i = OWN azimuth of SSR to BCAS (DAZ)
α_i = differential azimuth (DAZ)
T_i = the time of arrival (TOA)
H = altitude of target
H_o = altitude of BCAS

The initially (unknown) quantities describing the configuration are:

S_i = slant distance between SSR and target
D_i = slant distance between SSR and BCAS

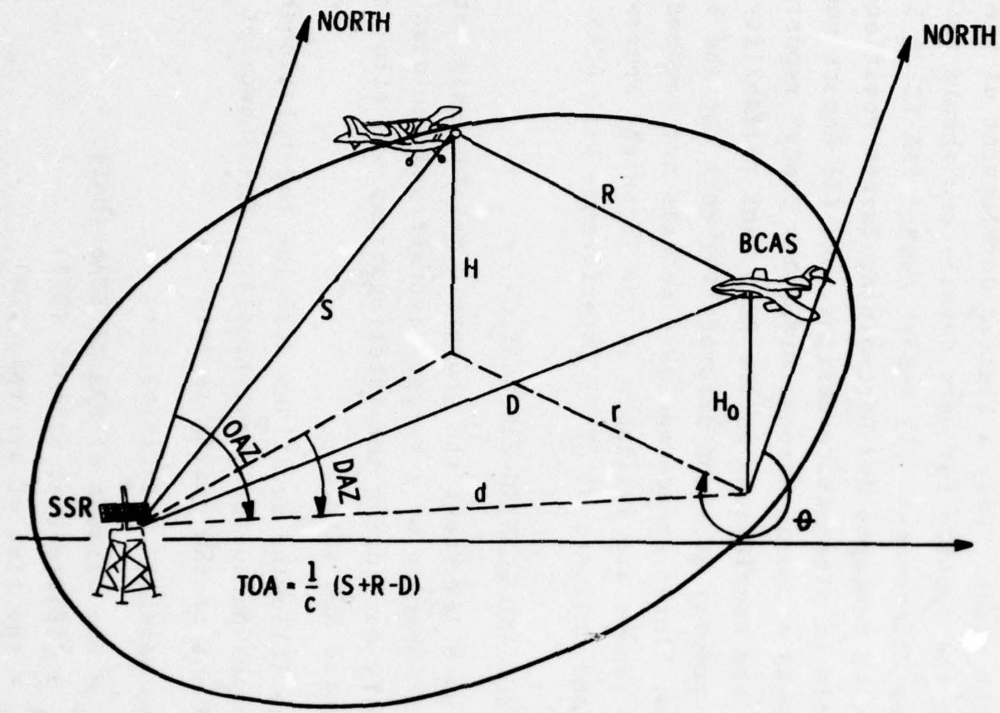


FIGURE 3-1. SINGLE SITE GEOMETRY

R = slant distance between BCAS and target

θ = bearing of target from BCAS

Then the TOA, by definition, satisfies

$$T_i = \frac{1}{c}(S_i + R - D_i) \qquad 3.2.1$$

By the law of cosines, the differential azimuth (DAZ) satsifies

$$\cos \alpha_i = \frac{s_i^2 + d_i^2 - r^2}{2\, s_i d_i} \qquad 3.2.2$$

$$= \frac{S_i^2 + D_i^2 - R^2 - 2HH_o}{2\sqrt{(S_i^2 - H^2)(D_i^2 - H_o^2)}}$$

It follows from the law of sines that

$$\sin(\beta_i - \theta) = \frac{s_1}{r} \sin \alpha_i = \qquad 3.2.3$$

$$= \sqrt{\frac{S_i - H^2}{R^2 - (H - H_o)^2}} \sin \alpha_i$$

This last equation (3.2.3) could be used to eliminate S_i from (3.2.1) and (3.2.2). This would leave a set of two equations relating the BCAS measurements T_i, α_i, and β_i to the three unknown R, θ, and D_i. This set of equations can not be solved without data from additional measurements. The measurements from two (or more) interrogators are required to solve for R, θ and D_i. Alternatively if R is determined by active measurement, then θ can be determined from the TOA, DAZ and OAZ measurement from a single site.

The following design concepts were evaluated.

1. Passive Mode BCAS; two design options:
   (a) The azimuth reference signal based concept where two ground interrogators and a simple target define the minimum system.

(b) The no-azimuth reference signal based concept, where two ground interrogators and two targets define the minimum system.

2. Mixed Mode BCAS; Azimuth/No-Azimuth Reference Signal Combination.

   The azimuth reference signal is required for at least one of the interrogator sites. Two interrogators and also two targets define the minimum system.

3. Single-Site BCAS.

   A single interrogator site with azimuth reference signal, a single target, and BCAS active mode interrogation define the system.

The solution of the sets of equations arising in each of these systems is discussed in detail in Reference 3.

The major emphasis was placed on the study of whether the azimuth reference signals from SSR sites are necessary. A comparison of the alternative techniques was conducted based on the accuracies in determining the range and bearing to a target from BCAS equipped aircraft.

3.2.1 Passive Mode BCAS with Azimuth Reference Signals

A significant part of the analysis was devoted to the assessment of the operation of the BCAS passive mode using azimuth reference signals emitted by the ground interrogator sites. The only case considered included two radar sites and a single target. An algorithm was developed and implemented on a FORTRAN-coded computer program for the TSC time-share computer system to compute range and bearing to a target from the inputs using data collected in-flight and from translated data.

The results of these tests and the associated analyses are the following.

1. In the absence of measurement noise, the relative position of the aircraft and radars can be determined exactly from the BCAS measurements, unless multiple solutions occur.

2. There exist distinct and different pairs of configurations of radars and aircraft in which the BCAS will receive identical sets of measurements, even in the absence of measurement noise. If the BCAS receives a set of measurements that may correspond to either of several configurations, there is no basis within the set of measurements pertaining to one aircraft at one instant of time for selecting the actual configuration correctly. If more data become available, either by observing other aircraft replying to the same radars or observing the same aircraft over an interval of time, it may become possible to resolve the ambiguity.
3. When measurement noise is present, the effect of the noise on the accuracy with which the relative positions of the aircraft and radars can be determined is a function of the configuration. Assuming measurement errors in TOA, DAZ and OAZ of the magnitude experienced by the experimental BCAS, the errors in the computed position of the other aircraft were less than 100 meters for a wide range of "good" configurations. They were sometimes much larger in the "bad" ranges, as discussed below.

3.2.1.1 Multiple Solutions - The reason multiple solutions come about can be explained in terms of a sequence of geometric arguments.

Geometrically, the measurements from one SSR relate the position of the target aircraft to that of the BCAS in the following way:

For a given OAZ and a given separation d between the radar and the BCAS, the TOA determines an ellipsoid of revolution on which the target must lie. The radar and the BCAS are at the foci of this ellipsoid. The differential azimuth determines a vertical plane passing through the radar and the target. The target altitude determines its horizontal plane.

For a given value of d, the position of the target aircraft is the intersection of these loci. Thus, the intersection of the TOA ellipsoid with the altitude plane is an ellipse E in the altitude plane.

The target must be where the ellipse is intersected by the vertical plane determined by the DAZ. If the radar lies within the ellipse E (projected to ground level), then there is only one such intersection and the target position is uniquely determined (for the assumed value of d). If the radar lies outside this ellipse, there are two intersections, and a target at either would result in the same measured values of TOA and DAZ (again for the assumed value of d). This second condition can be visualized as coming about if the TOA ellipsoid is long and inclined, cut by the horizontal altitude plane at the end away from the radar. (In fact, a necessary algebraic condition for the multiple solution to occur is that $c \cdot (TOA) < H$, where c is the speed of light).

In the normal passive BCAS operation, the distance d of the BCAS to the radar is not given. Different values can be assumed, and for each value the position(s) of the target corresponding to the measurement set can be constructed. As the assumed radar-to-BCAS distances ranges over all possible values, these possible target positions form a curve of two distinct curves, which are the locus of possible positions of the target consistent with the known BCAS and target altitudes and the measurements of TOA, DAZ, OAZ for the one radar. Similarly, the locus of possible target positions can also be constructed for another radar. The target position must be consistent with both sets of measurements; hence the target must be at a position where the locus curves intersect. If the set of requirements for each radar gives rise to only one locus curve, the target position is uniquely determined as the intersection of these two curves. If, however, one or both sets of measurement gives rise to two distinct locus curves, then more than one intersection is possible, as seen in Figure 3-2 (Reference 3, Sections 2 and 5).

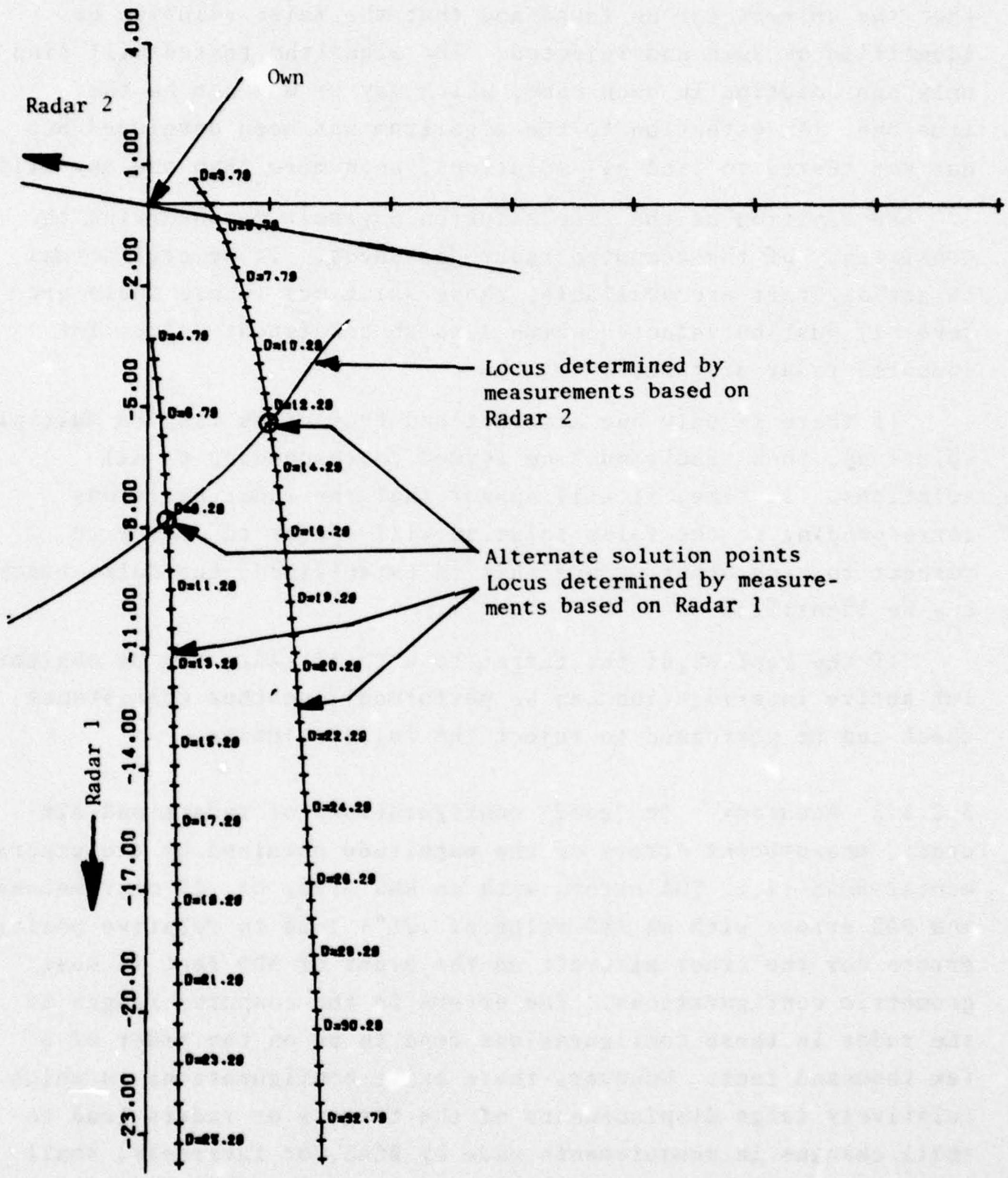


Illustration of case of two possible solutions for target position, given measurements from two radars with azimuth reference signals and one target.

FIGURE 3-2. MULTIPLE TARGET SOLUTION

In cases when multiple solutions exist, it is important that the correct one be found and that the false solution be identified as such and rejected. The algorithm tested will find only one solution in each case, which may or may not be the true one. An extension to the algorithm has been developed but not yet tested to find all solutions, when more than one may exist.

Recognition of the true solution may rest on observing the consistency of the computed radar distances. If several actual target aircraft are available, those solutions (where there are several) must be selected which lead to consistent values for computed radar distances.

If there is only one aircraft and that gives rise to multiple solutions, then tracks must be formed corresponding to all solutions. In time, it will appear that the radar positions corresponding to the false solution will appear to move with respect to each other. Once this is established, the false track can be identified.

If the replies of the target to a third radar can be monitored (or active interrogation can be performed), another consistency check can be performed to reject the false solution.

3.2.1.2 Accuracy - In "good" configurations of radars and aircraft, measurement errors of the magnitude obtained by the experimental BCAS (i.e. TOA errors with an RMS error of .15 microseconds and DAZ errors with an RMS value of .25°) lead to relative position errors for the other aircraft on the order of 300 feet in most geometric configurations. The errors in the computed ranges to the radar in these configurations tend to be on the order of a few thousand feet. However, there exist configurations in which relatively large displacements of the targets or radars lead to small changes in measurements made by BCAS, or inversely, small changes in measurements lead to large changes in the configuration corresponding to the measurement set. This means that the values of range and bearing calculated from noisy measurements will show

large deviations from their actual values as a result of random measurement errors. In some cases, the iterative *algorithm may* fail to converge.

The configurations which may generate poor results are the following:

1. Both radars in the same direction from the BCAS aircraft (OAZ_1-OAZ_2 less than $\sim 10°$).
2. The intruder aircraft between the BCAS and one of the ground radars ($|\beta_1-\theta|$ less than $\sim 15°$).
3. The intruder aircraft in the direction opposite the radar from BCAS ($|\beta_i-\theta-180°|$ less than $\sim 3°$).

3.2.2 Passive Mode BCAS Without Azimuth Reference Signals

A purely passive BCAS system without azimuth reference signals can operate when there are two radars and two targets.

Since all the measurements available to the system are invariant under rotation of the whole configuration, the bearing of one radar may be specified arbitrarily. The three relative bearing angles in the configuration are defined in terms of the arbitrary reference direction.

The quantities measured are four TOA's, four DAZ's, and three altitudes, or eleven measurements in all.

The interrelationship between measured and derived parameters is shown in Figure 3-3.

Solutions to be found are for the parameters describing the configuration. These are two distances to the ground interrogators from OWN, two distances to both targets, three bearing angles and three aircraft altitudes, or ten parameters in all. Thus, the problem is overdetermined.

The method of solution is complicated and consists of a number of steps. At the end, a solution is sought which in a useful sense is a best fit to the data. The solution proceeds in three separate

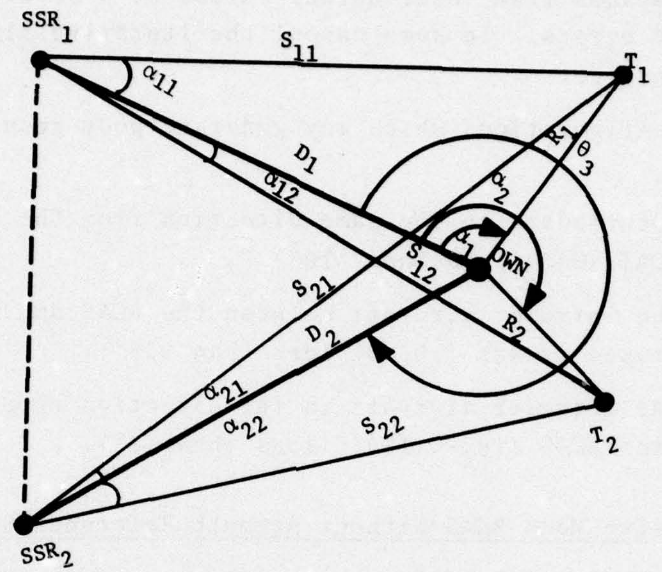


FIGURE 3-3. MEASURED AND COMPUTED PARAMETERS

essentially independent steps - coarse initialization, iterative refinement, and least-squared-error fitting. The details of the algorithm are discussed in Reference 3. An outline describing the nature of the steps is presented below.

Step 1: The coarse initialization is based on the simplifying assumptions that the BCAS-to-target distances are much smaller than the BCAS-to-radar distances and that all aircraft altitudes can be neglected. These simplifications allow the inherently non-linear set of 8 equations

$$T_{ij} = S_{ij} + R_j - D_i \qquad 3.2.4$$

$$\cos\alpha_{ij} = \frac{S_{ij} + d_i^2 - r_j^2}{2S_{ij}\, d_i} \qquad 3.2.5$$

$$(i=1,2;\ j=1,2)$$

to be reduced by various algebraic manipulations and successive elimination of variables to a pair of simultaneous linear equations that is solved for the target distances r_1 and r_2. The original set of equations for this simplified case is still overdetermined (assuming the altitudes to be 0, there are 8 equations corresponding to the measurements to be solved for seven parameters defining the configuration). Therefore inconsistent sets of values can be obtained for the other variables defining the configuration, depending on the order in which the variables already solved for were substituted back into the equations to evaluate the others. The choice made is to determine each radar-to-BCAS distance on the basis of the greater DAZ (so as to minimize the percentage error due to measurement errors). The other quantities are computed in an essentially random order, with no attempt made to minimize the resultant inconsistencies.

Step 2: The coarse initialization obtained in Step 1 serves as the initial configuration to be improved iteratively in Step 2. The main goal of the process is to take into proper account the aircraft altitudes, neglected during Step 1. Further, explicit note is taken of the fact that the system of equations is overdetermined.

The calculations are performed iteratively. The distances and angles are computed for the projection of the 3-dimensional configuration of the aircraft on the horizontal plane. The effect of the aircraft altitudes is taken into account by modifying the measured values of TOA to compensate for the altitude.

One may note that the TOA

$$T = \sqrt{s^2 + H^2} + \sqrt{r^2 + (H-H_o)^2} - \sqrt{d^2 + H_o^2} \qquad 3.2.6$$

$$= s + \varepsilon_S + r + \varepsilon_r - d - \varepsilon_d \qquad 3.2.7$$

where

$$\varepsilon_S = \sqrt{s^2 + H^2} - s \tag{3.2.8}$$

$$\varepsilon_R = \sqrt{r^2 + (H-H_o)^2} - r \tag{3.2.9}$$

$$\varepsilon_D = \sqrt{d^2 + H_o{}^2} - d \tag{3.2.10}$$

H - altitude of target

H_o - altitude of BCAS

One can therefore write a simplified, apparently linear TOA equation

$$t = s + r - d \tag{3.2.11}$$

where

$$t = T - \varepsilon_S - \varepsilon_R + \varepsilon_D. \tag{3.2.12}$$

At each step of the iteration, the value of t is recomputed on the basis of the best current estimates of s, r and d until convergence is achieved - i.e., until the values do not significantly change from step to step. (In certain "bad" configurations the process does not converge and it is therefore always terminated after some fixed number of iterations.)

A set of three independent equations in the two unknowns d_1 and d_2 is developed. This overdetermined system is solved at each iterative step in the following way:

Three equations developed on the basis of geometric arguments require that:

$$\begin{aligned} F_1(d_1, d_2) &= 0 \\ F_2(d_1, d_2) &= 0 \\ F_3(d_1, d_2) &= 0 \end{aligned} \tag{3.2.13}$$

where F_1, F_2, and F_3 are functions only of the BCAS-to-radar distances (d_1 and d_2), the measured differential azimuths, and (the best current estimates of) the adjusted TOA (Equation 3.2.6).

These equations are mutually inconsistent - i.e., for any pair of values (d_1, d_2), not all three functions F_1, F_2, F_3 will be identically zero, but rather they will have values

$$\begin{aligned} F_1(d_1, d_2) &= e_1 \\ F_2(d_1, d_2) &= e_2 \\ F_3(d_1, d_2) &= e_3 \end{aligned} \qquad 3.2.14$$

such that

$$E = (e_1^2 + e_2^2 + e_3^2) \neq 0 \qquad 3.2.15$$

At each step, the iterative algorithm determines changes (Δd_1, Δd_2) to d_1 and d_2 such as to reduce E, the measure of the inconsistency of the equations.

The changes (Δd_1, Δd_2) are computed as follows: The equations are made into linear equations in Δd_1 and Δd_2.

$$F_i\ (d_1 + \Delta d_1,\ d_2 + \Delta d_2) \qquad 3.2.16$$

$$= F_i\ (d_1, d_2) + \frac{\partial F_i}{\partial d_i} \Delta d_1 + \frac{\partial F_i}{\partial d_2} \Delta d_2$$

$$= m_i\ (\Delta d_1, \Delta d_2)$$

One seeks the values of Δd_1 and Δd_2 which minimize

$$E\ (\Delta d_1, \Delta d_2) = \sum_i e_i\ (\Delta d_1, \Delta d_2)^2 \qquad 3.2.17$$

The minimum occurs when

$$\frac{\partial E}{\partial \Delta d_j} = 0 \qquad (j = 1,2) \qquad 3.2.18$$

This is a set of two linear equations in the two unknown Δd_1 and Δd_2. Its solutions are used to improve the current values of d_1 and d_2, to compute the other parameters that determine the configuration from these, and to update the values of the adjusted TOA's. The iterative step is then repeated until convergence is obtained (or failure to converge is evident).

When this process is used to compute the configuration from simulated noise-free measurements, perfect results are obtained (where the process converges). When noisy measurements are used (i.e. in the practical case), then reasonably good fits to the actual configuration are obtained. However, these are not the best fits to the data. Furthermore, as in the case of Step 1, the parameters defining the configuration are determined by first finding one pair of them - here d_1 and d_2 - and then determining the rest successively by substituting the values of the parameters already solved for into expressions involving the others. Since the overall set of equations is overdetermined, the values obtained will not in general be consistent. No attempt is made in this step to resolve these inconsistencies. The theoretically optimum solution is obtained by Step 3, for which the results obtained here serve as initial values.

Step 3: The final step is again an iterative squared-error minimization process. The eleven quantities measured by BCAS are expressed as functions of the ten various coordinates defining the radar-aircraft configuration.

$$y_\ell = F_\ell (X) \tag{3.2.19}$$

where y_ℓ is the ℓ-th measurement and $X = (X_1 \ . \ . \ . X_{10})$ is the vector of coordinate values defining the radar aircraft configurations. The components of X are the two BCAS-to-radar distances, the two BCAS-to-aircraft distances, the three relative angles to aircraft and radar from the BCAS, and the three aircraft heights. The y_ℓ are the following: four TOA's, three reported altitudes, and for each radar the sum and difference of the differential azimuths of the two target aircraft relative to that radar. (The sum and differences of the DAZ's are used, rather than the DAZ's

themselves, because there is correlation between the measurement noise components of the DAZ's, but not between the noise components of their sums and differences.)

The actual measurements m_ℓ are noise corrupted, so that there will be a random discrepancy e_ℓ between the predicted value y_ℓ of a given measurement when the configuration is described by a given set of parameters X and the actual measurement m_ℓ.

$$e_\ell = m_\ell - y_\ell(X) \tag{3.2.20}$$

This discrepancy e_ℓ is ascribed to measurement error. By what is known as the principle of least squares, the assumed configuration bests fits the measurement data when

$$E = \sum_\ell \frac{e_\ell^2}{\sigma_\ell^2} \tag{3.2.21}$$

$$= \sum_\ell \frac{(m_\ell - y_\ell(X))^2}{\sigma_\ell^2} \tag{3.2.22}$$

is minimized (where σ_ℓ^2's are the variances of the independent errors in the measurements).

The X minimizing E is found iteratively. The set equations for the errors are first made into a set of linear equations in terms of ΔX, incremented changes about the true minimum configuration. The set of equations is of the form

$$\frac{m_\ell - F\,(X_{opt})}{\sigma_\ell} = \sum_k \frac{\partial F_\ell}{\partial X_k} \tag{3.2.23}$$

The partial derivatives are evaluated at the current best approximation of the true configuration. Temporarily holding these partial derivatives fixed, standard multivariate regression techniques are used to find the ΔX that minimizes E. The set of

coordinates X is then corrected by adding the computed ΔX and the process is repeated until it converges - i.e. until successive ΔX's become sufficiently small.

3.2.2.1 Overall Assessment of the System Without Azimuth Reference Signals - Simulations were conducted to see how the BCAS would perform from the measurements based on radars without azimuth reference signals. The accuracy of the computed relative positions in "good" configurations was found to be equivalent to that achieved using the system with azimuth reference signals. As in the case of radars with azimuth reference signals, there are ranges of configurations in which the solutions are inherently very sensitive to measurement errors. These configurations include the following:

1. when the two radars are colinear when viewed from the BCAS
2. when either of the target aircraft is in between the BCAS and one of the radars
3. when the BCAS is directly between either target aircraft and one of the radars
4. when the BCAS aircraft and both target aircraft are in a line.

The extent of each bad range is a function of the total configuration. Two target aircraft are involved, and the unfavorable placement of either can make the whole configuration "bad". It appears that the probability that a configuration will be "bad" is therefore greater for the no-azimuth-reference system than for a system based on azimuth reference signals requiring only one target aircraft for solution.

Aside from the inherent inaccuracy of the solutions in certain configurations that arises from the nature of the relationship of the configuration to the measurements (large changes in configuration correspond to small changes in the measurements), there are still difficulties with the solution algorithms as currently implemented.

The final iterative least-square fitting process (Step 3) will converge only if the initial approximation to the configuration is close enough to the final configuration. Trial simulations showed that neither Step 1 nor Step 1 and Step 2 in combination always resulted in sufficiently good approximations. In a series of trials, using ten sets of noisy measurements at each of 216 different configurations, it was found that roughly 70% of the time either the coarse initialization (Step 1) by itself or in combination with Step 2 gave a good initial approximation, and some 18% of the time neither did. The rest of the time, one or the other process gave a good initialization, but not both. Thus there is seen to be room for improvement in both processes. However, most of the cases of failure to achieve a good initialization occurred in configurations in which the final and theoretically best achieveable fit was in any case highly error-sensitive.

3.2.2.2 Orientation of the Whole Configuration - Only relative angles are computed in the no-azimuth-reference-signal system considered above. To detect threats and select evasive maneuvers, we must determine the bearing of targets relative to the OWN aircraft flight direction.

Two possible schemes to do this were considered. First, one can compute OWN's position relative to the radars at a number of successive observation times. Then the known direction of OWN flight can be related to the fixed direction of the line connecting the radars. Then, whenever a configuration is computed, all bearings can be related to this fixed line. The simulations that were conducted showed that bearings relative to the line of positions of the radars could be calculated accurately to within an error of generally less than a degree, given the expected measurement errors. The dynamic calculations of establishing the direction of this line from the known direction of OWN flight were not simulated. The process must by its nature take some time.

An alternative, instant way of establishing all bearings exists if in every region at least one ground radar emits azimuth reference signals. If only one such radar is available, then the determination of the shape of the radar-aircraft configuration must be carried out by the technique described for no azimuth reference signal, but the known (measured) bearing of the radar from OWN can then be used to orient the whole configuration immediately.

3.2.3 Solution of Single-Site BCAS Equations

The situation was considered that the BCAS may be locked to a single radar, which is assumed to furnish azimuth reference signals. The information to be derived from passive listening-in to only one radar is insufficient to determine the position of the target. A solution for target bearing and radar range is possible if measurements of target range obtained by active mode interrogation are combined with the passive mode TOA, OAZ and DAZ measurements from the one radar.

Two algorithms have been developed to perform this calculation. One is an iterative scheme relying on geometric arguments (Reference 3, Section 4). The other technique involves the exact solution of the equations relating the configuration parameters and the measurements. In particular, a fourth-order algebraic equation (polynomial) is developed in the argument X, where X is the sine of an angle related to the target bearing angle. The equation is solved exactly (by formula). The real roots (when more than one is obtained) are tested for consistency with the geometric constraints to obtain those which correspond to the actual solution. Limited simulations have been performed using this algorithm.

It has been established that bearing accuracies comparable to those for the purely passive schemes are obtained in the presence of measurement errors. Multiple solutions occur in some configurations which are consistent with all the measurements. These come about in essentially the same way as those which occur with the two-radar passive solution found for radars with azimuth reference signals (Section 3.2.1.1). There are two "bad ranges", centered

on target positions which have the radar and the BCAS and target aircraft colinear.

Sample runs were conducted, simulating a BCAS aircraft 20 miles from a radar, and a target 3 miles from the BCAS. Both when the target was between the BCAS and the radar and when it was roughly in the direction opposite from the radar, the width of the bad range was some 40°. In the bad range, the bearing error was on the order of several degrees. Elsewhere it was generally less than one degree.

3.3 SYNCHRONOUS GARBLE ANALYSIS

3.3.1 BCAS Active and Passive Mode Synchronous Garble

Synchronous garble is caused by the coincidence of two reply messages in time. It is a more severe problem for BCAS than it is for the ATCRBS system. The active BCAS both interrogates and receives target replies via an omni antenna, while ATCRBS interrogates and receives replies only within a 4° wide beam. Since the ATCRBS reply is 20.3 microseconds long, the active BCAS will get overlapping replies to an interrogation from any pair of aircraft located anywhere in a spherical shell centered at the BCAS and 1.6 nautical miles thick. The problem of synchronous garble, among others, serves to restrict the use of active BCAS to regions of relatively low traffic density.

Synchronous garble may also occur in passive BCAS operation when the target aircraft are being interrogated by a ground SSR. However, the replies from two targets will arrive garbled at a passive BCAS only if the target locations satisfy a more extensive set of conditions. Two targets will garble only if they lie in the same interrogator beam-width and also on the ellipsoidal constant-TOA surfaces that correspond to TOA's separated by less than 20.3 microseconds. The volume of such airspace depends in a complicated way on the radar and aircraft geometry, but is in general smaller than for the active BCAS.

Another way to assess the likelihood of synchronous garble is to assume a configuration of two target aircraft and to then consider the volume of airspace within which a BCAS aircraft would receive their replies synchronously garbled.

For an active BCAS, there is always a region in which it will receive the replies of two targets synchronously garbled. This region lies about the plane of symmetry separating the two targets. Regardless of how far apart the targets are, an active BCAS equidistant from both will necessarily receive their replies completely overlapped. There will be partial overlap of the replies as the BCAS moves off the plane of symmetry, and if the targets are sufficiently far apart, the BCAS will receive their replies in the clear. The boundaries between the region in which the BCAS receives the replies in the clear and in which they arrive overlapped is hyperbolic (see Figures 3-4 to 3-9). The region in which reception is garbled becomes more extensive as the targets come closer together. When they are within 10,150 feet or less, it encompasses all space.

For passive BCAS, there is no synchronous garble unless both target aircraft are illuminated by the same ground SSR beam. If two target aircraft are colinear with an SSR interrogator, there always exists a region in which their replies are received garbled. The size of this region depends on the separation of the aircraft; its shape is that of a hyperboloid of revolution whose focus is one of the aircraft. Independent of the distance between the two aircraft, their replies will totally overlap in time along the extension of the line of position of the radar and the two aircraft beyond the farther aircraft. If the aircraft are far apart, there is a narrow region, hyperbolic and convex toward the radar, within which the replies will be received at least partly overlapped. This region becomes wider when the planes are closer together, and ultimately become concave toward the radar for separations less than 20,300 feet.

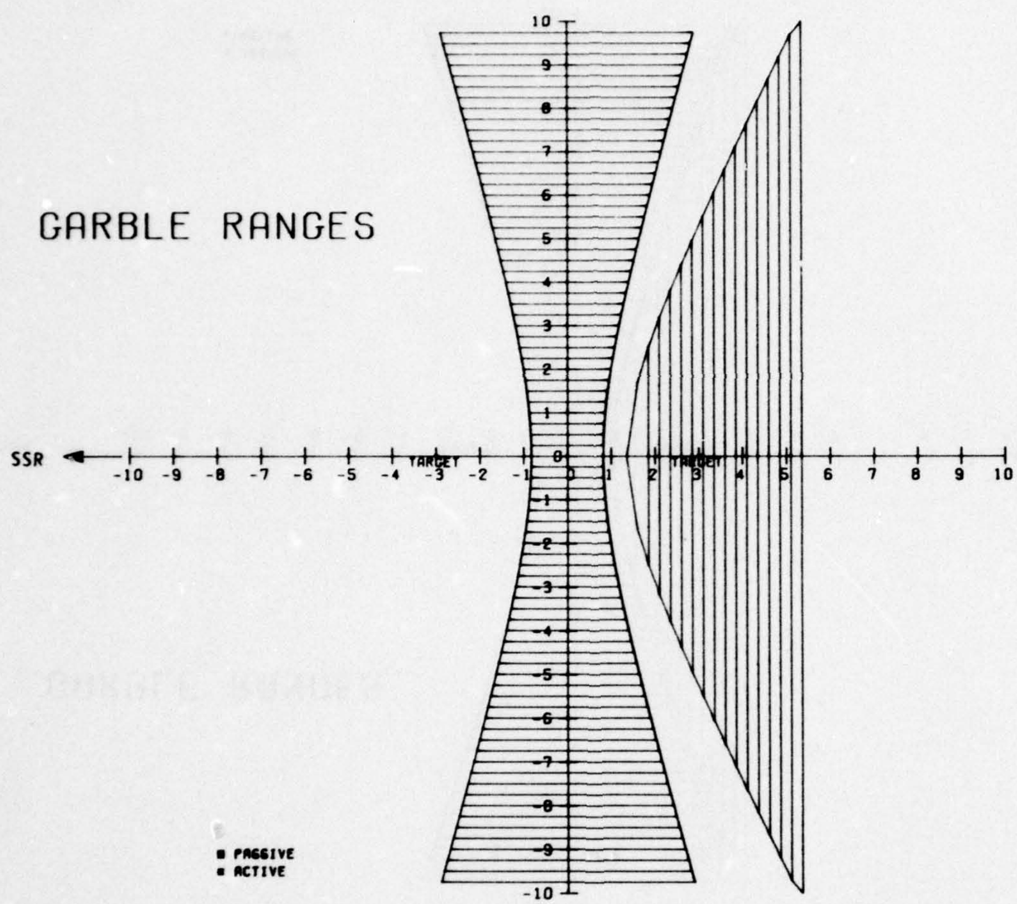


FIGURE 3-4. GARBLE ZONES FOR THE 6 MILE SEPARATION

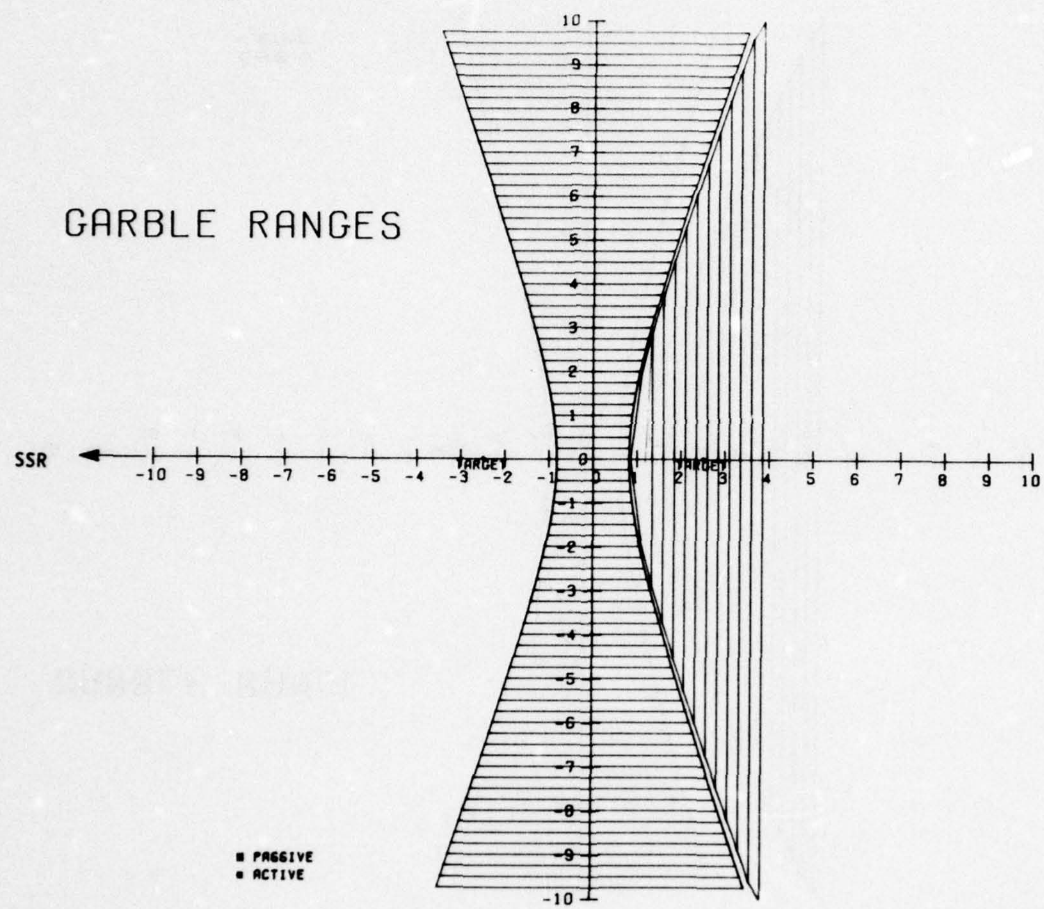


FIGURE 3-5. GARBLE ZONES FOR THE 5 MILE SEPARATION

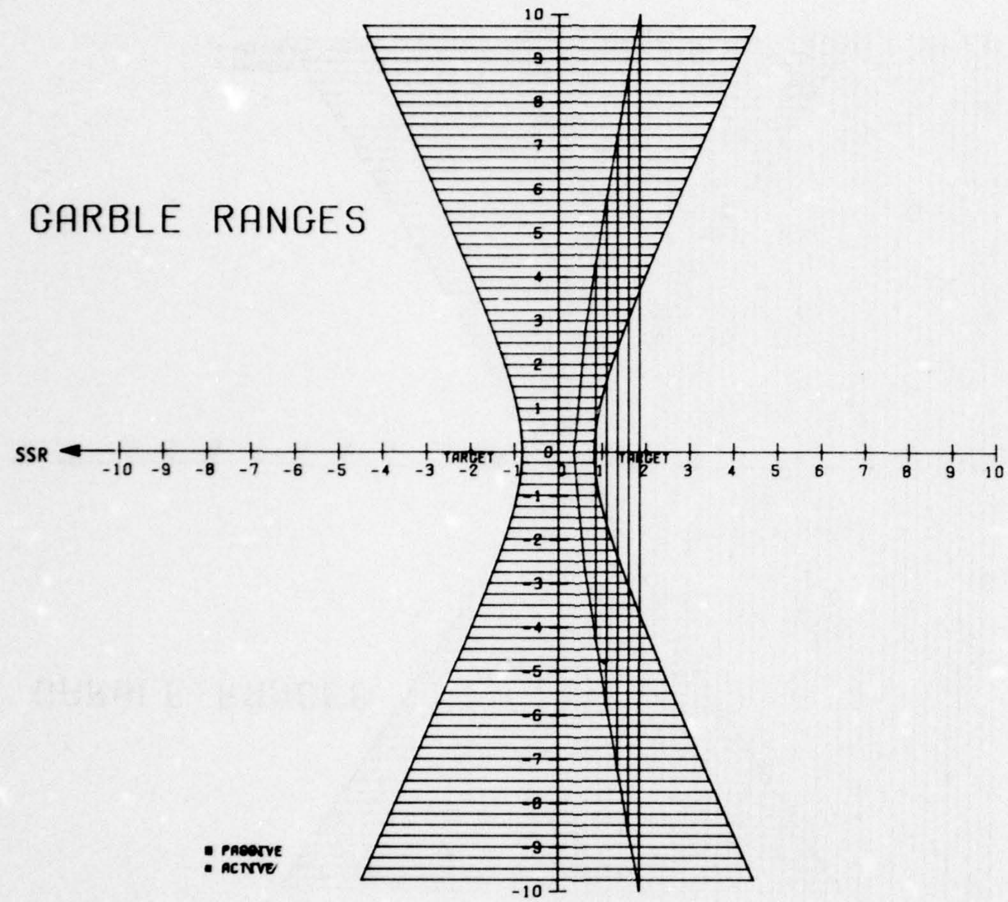


FIGURE 3-6. GARBLE ZONES FOR THE 4 MILE SEPARATION

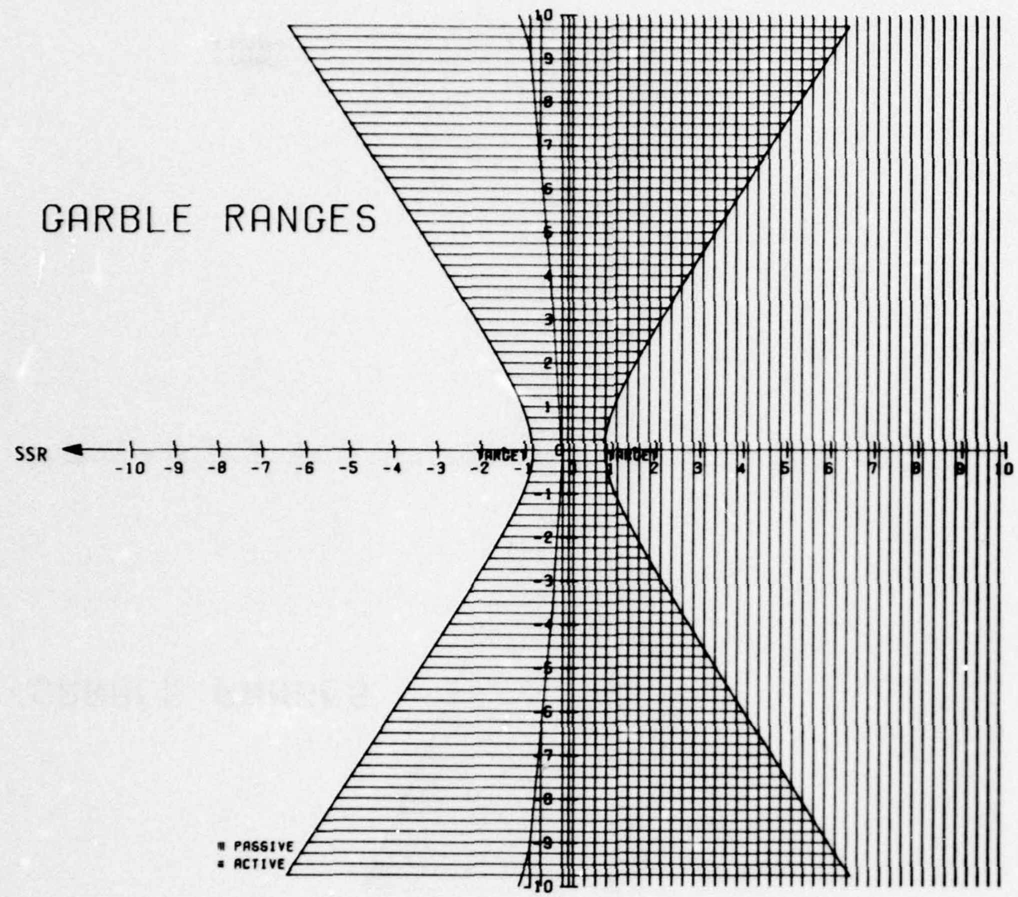


FIGURE 3-7. GARBLE ZONES FOR THE 3 MILE SEPARATION

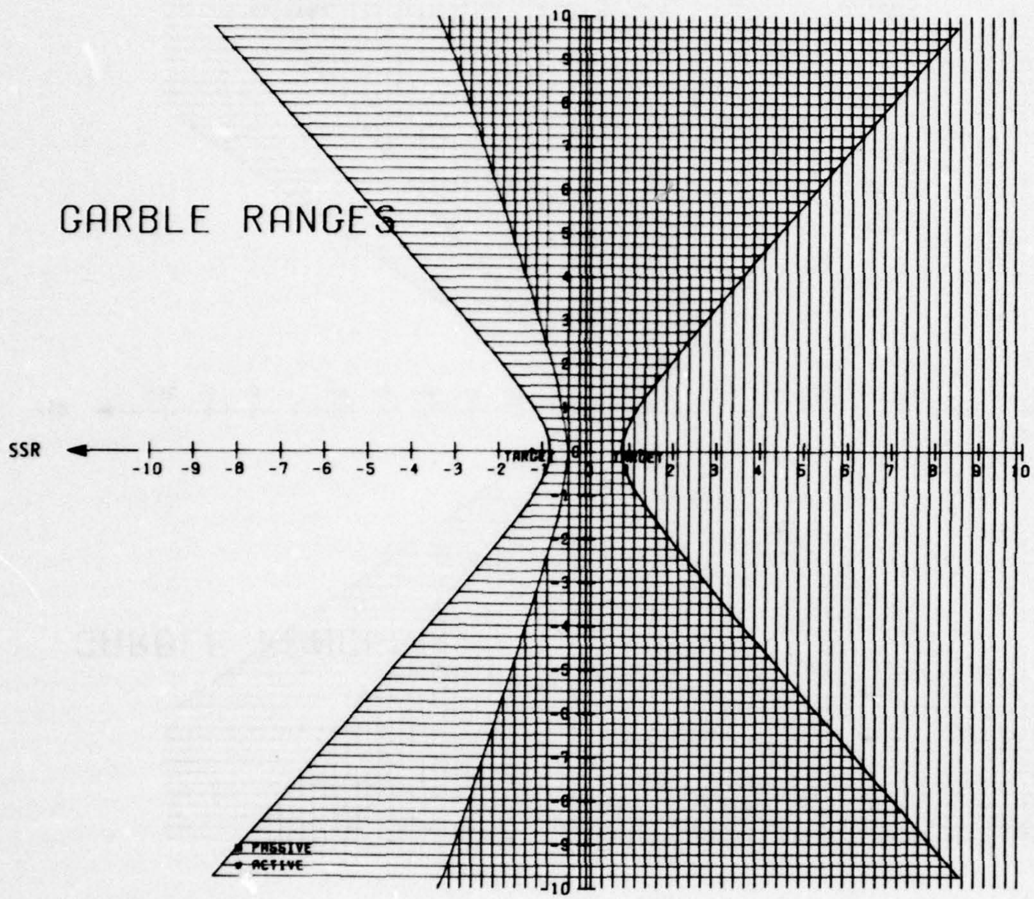


FIGURE 3-8. GARBLE ZONES FOR THE 2.6 MILE SEPARATION

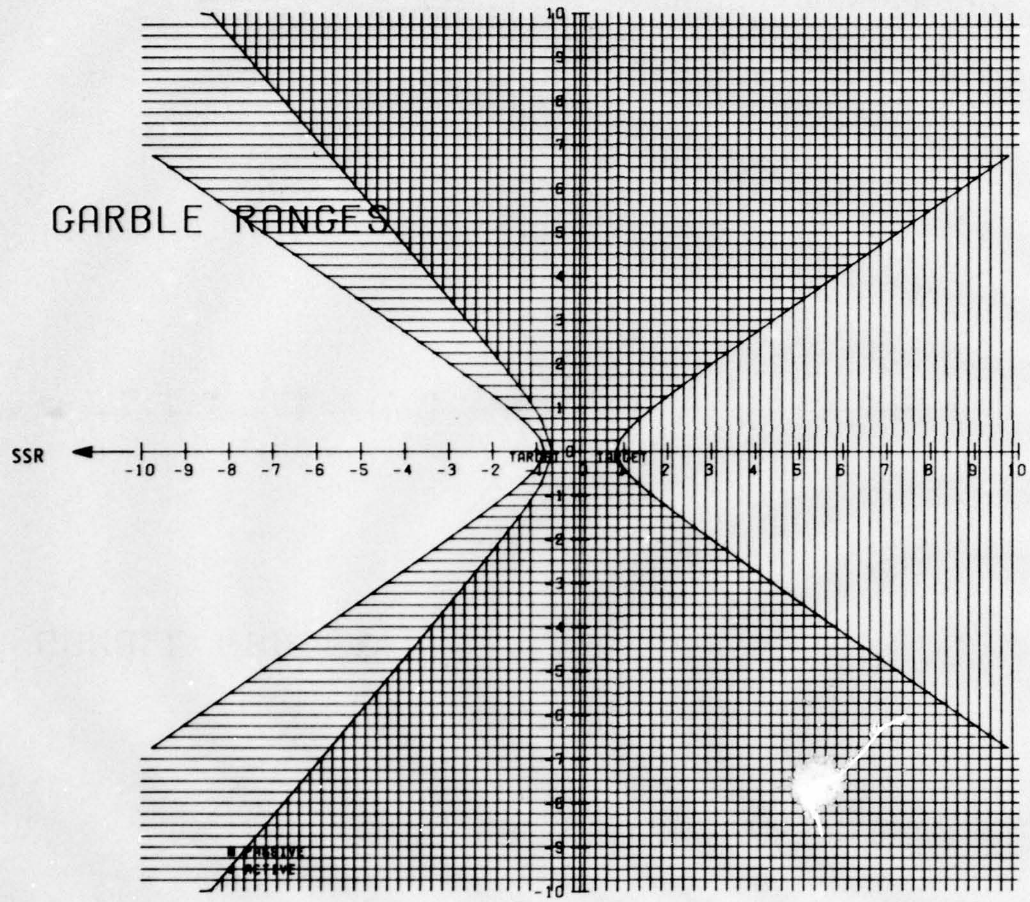


FIGURE 3-9. GARBLE ZONES FOR THE 2.1 MILE SEPARATION

When the aircraft come within 10,150 feet (still colinear with the SSR), the region in which their replies overlap encompasses all space.

Figures 3-4 to 3-9 illustrates the shape of the regions in which an active BCAS (vertical shading) and a passive BCAS (horizontal shading) will receive target replies garbled. The figures are plotted for various target separations. The targets and BCAS are assumed to lie in the plane of the diagrams. For passive BCAS, the radar is assumed in the same plane and colinear with the targets. (There is no passive mode garble unless the targets and the radar are aligned.)

Within the garble regions, the extent of the reply overlap varies between complete message coincidence (for active BCAS, on the line of symmetry; for passive BCAS, colinear with the targets and beyond them, when viewed from the radar) to shifted replies just touching (along the hyperbolic boundaries of the garble regions).

For the passive BCAS, flight tests have shown that the synchronous garble phenomenon does occur, but that even in the presence of synchronous garble, the experimental system was able to decode properly 38% of the target replies.

3.4 BCAS/ATCRBS/MONOPULSE COMPATIBILITY

A number of improvements/modifications are being implemented or planned to improve the performance of the ATCRBS system. In FAA Order 6360, Air Traffic Control Radar Beacon System (ATCRBS) Improvments Program, the various planned improvements/modifications were classified into fourteen (14) categories. In Appendix A, these 14 categories were examined to determine which ones have a potential impact on BCAS operation and deserve further studies and evaluating.

In Table 3-1 are listed the selected categories which were judged to have a potential impact on BCAS operation. Categories IA.3 and IC.5 pertain to improvements affecting BCAS coverage.

TABLE 3-1. ATCRBS IMPROVEMENTS/MODIFICATIONS WITH POTENTIAL IMPACT ON BCAS OPERATION

Category	Relevant Improvements	Potential Impact on BCAS	Action Required
I. A.3(a) Power Reduction	a) Reduce Power to Minimum Requirements	a) Reduces Coverage Area	a) Assess Impact on Coverage-Range of SLS Signals.
C.5(b)(c) Interrogator Modifications	b) Azimuth Gate Power Output c) Trevose Fix	b) Reduce Coverage at Some Azimuth c) Suppresses Transponder Replies at Some Azimuth. - Impact Unknown	b) Site Specific Coverage Analysis c) Site Specific Study and Analysis
II. C.1(b) Improved Antenna	b1) "Integral"; SLS b2) Monopulse Operation	b1) *Unknown* - signals radiate in restricted azimuth b2) Unknown-Fewer Pulses Per Scan	b1) *Assess Impact of* "Integral" SLS antenna pattern b2) Assess Impact of Monopulse Operation

Reduction of transmitted power to minimum required levels (to minimize interference) would reduce the coverage area. The other interference reducing improvements are site specific and should be analyzed as such.

Category IIC.1 appears to be the main category with a major potential impact on BCAS operation. This improvement/modifications involves the incorporation of a monopulse antenna into the ATCRBS system. The antenna may also utilize an "integral" feed to generate the side lobe suppression (SLS) pattern. An "integral" antenna feed system would provide a better match between the main beam (MB) and the SLS vertical lobing pattern. These improvements/modifications, if incorporated into the ATCRBS system, may result in the following:

a. In monopulse operation fewer interrogation and target reply pulses would be generated per scan.

b. In an "integral" antenna system, the transmitted SLS signals would be available in a resitricted azimuth only.

In the passive mode of operation, BCAS operates on the main beam interrogation and SLS signals for locking to ground radars, timing, target detection and measurements of basic parameters such as BCAS own azimuth, differential azimuth, SSR scan period and the time of arrival of target replies. An evaluation of the impact of the above ATCRBS improvements/modifications on BCAS parameters and performance has been initiated.

4. FLIGHT TEST

During a nine month period approximately 100 BCAS flights were flown at the FAA National Aviation Experimental Center (NAFEC), Atlantic City, New Jersey. These flights were in support of evaluation of the BCAS system, the development of the system by the contractor, system demonstrations, azimuth reference signal studies, and JITS compatability studies. Over 200 hours of flight test data was recorded for use in the analysis of the system. While flying a variety of test patterns, the BCAS system was operated in the passive mode, active mode, and a combination of both. Test patterns included two aircraft encounters (BCAS and other) flying level, curved and climb/drive paths. Flights were tracked by the Extended Area Instrument Radar (EAIR), Phototheodolytes, and the Automatic Radar Terminal System (ARTS III). The following paragraphs describe test bed, equipments, procedures and conduct, and test flight patterns.

4.1 FLIGHT TEST ENVIRONMENT - GENERAL

A flight test bed was established at NAFEC to provide as realistic an environment as possible and at the same time satisfy test program requirements. A flight range center staging area about the Millville, New Jersey Vortac was selected. This area was within a triangle formed by the Secondary Surveillance Radar (SSR) sites at NAFEC (ASR-4 and ASR-5), Philadelphia (ASR-7) and Newport, New Jersey (Transportable Beacon Siting Van) (Figure 4-1). This satisfied a primary test requirement that beacon sites be separated in azimuth from the BCAS aircraft by 90° or more. The Philadelphia ASR-7/BI-4 and NAFEC ASR-4/BI-3 are operational FAA terminal radar facilities, while the ASR-5/BI-3 at NAFEC is an experimental site which was operated in conformance with the U.S. National Beacon Standards. These three sites are tied into ARTS III terminal control facilities: Philadelphia ASR-7 with the Philadelphia ARTS III and the NAFEC ASR-4 and ASR-5 with the experimental ARTS III Terminal Automated Test Facility (TATF) located at NAFEC.

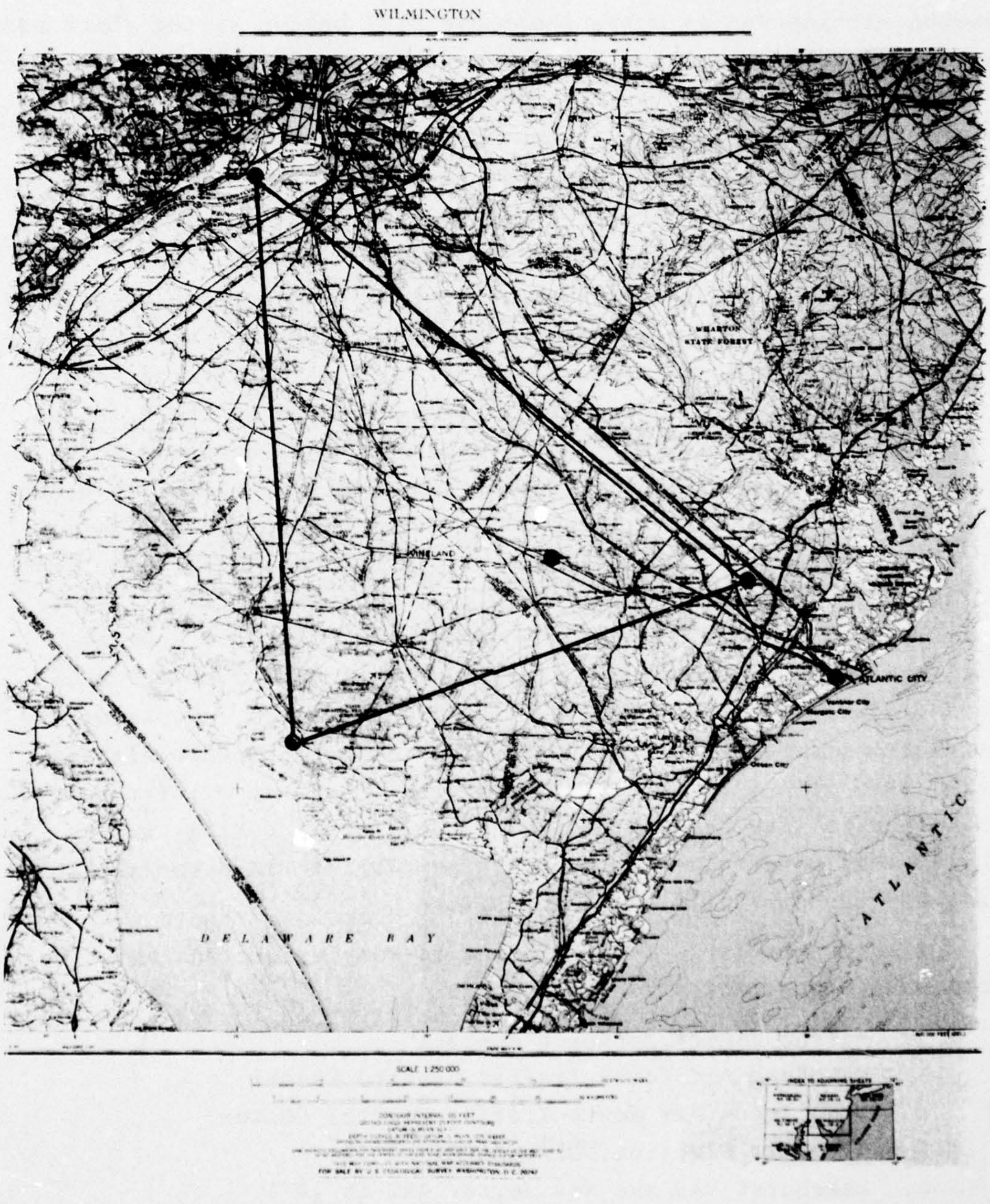


FIGURE 4-1. TEST AREA

Data recordings were made at both ARTS III facilities and used for multi-aircraft tracking and environmental investigations (gargle, azimuth reference pulse interference, fruit, etc.) The beacon sitting van is a transportable BI-4 beacon system which was initially set up at Bader Field, New Jersey and later relocated to Newport, New Jersey. The Van's flexibility in selection of PRFs, antenna rotation rates and output power allowed variations in the flight test conditions while still operating within the U.S. National Beacon Standard. These sites were modified to transmit azimuth reference pulses which were required by the BCAS.

A fixed target or "Parrot" was established at Mizpah, New Jersey using a reference transponder. This provided a fixed target at an accurately surveyed location. The BCAS aircraft would then "fly the parrot" while it was being tracked by the Extended Area Instrumentation Radar (EAIR). The raw EAIR data was rotated and translated to the coordinate system of the NAFEC ASR to which the BCAS was locked. Position coordinates of the Mizpah tower, relative to this ASR, were then obtained using a NAFEC geodetic position coordinates program. Values of Time of Arrival (TOA). Differential Azimuth (DAZ) and Own Azimuth (OAZ) were computed from the data and compared to the values recorded from the BCAS. This measurement technique was, in part, necessary because of the predicted accuracies of the BCAS system. The Phototheodolities, EAIR, ARTS III (NAFEC and Philadelphia) and air-to-air Tacan were used to establish the position of test aircraft during testing. The systems were selected for use depending on the purpose of the test and the capabilities of the systems.

Flight activity was coordinated to varying degrees with the following organizations:

a. Atlantic City Approach Control
b. New York Air Route Traffic Control Center
c. Washington Air Route Traffic Control Center
d. 20th Air Division, USAF ADC (W-107)
e. Lakehurst NAS and New Jersey ANG (W-107)
f. Patuxant River NAS (W-386A-B) (W-108)
g. Philadelphia Approach Control.

Early in the program, briefings were given to the appropriate organizations along with a set of flight patterns and airspace requirements. Direct contact was made with the appropriate personnel approximately seven (7) days prior to a specific flight and final coordination one (1) day before the flight. Any changes in flight patterns, airspace requirements, or departure and arrival times were accomplished by phone prior to the proposed departure time.

4.2 TEST BED CONFIGURATION

The BCAS equipment was installed on a NAFEC Grumman G-159 twin-engine turboprop aircraft. Two such aircraft (N-47, N-48) were used during the testing with the BCAS installed on either N-47 or N-48 except for a special test flight when two BCAS systems were installed, one on each aircraft. Other aircraft used as targets, were a Convair 580 (N49), an Aero Commander AC680-E (N50), and a Douglas DC-6 (N46). The BCAS included special antennas which were installed at top and bottom locations on N47 and N48 as shown in Figure 4-2. The ground facilities (see Figure 4-3 for the facilities at NAFEC) consisted of the following equipments:

1. ASR-5/BI-3 - NAFEC Experimental system.
2. ASR-4/BI-3 - FAA Eastern Region Facility, located at NAFEC.
3. ASR-7/BI-4 - FAA Eastern Region Facility, located at Philadelphia, PA.
4. Transportable Beacon Siting Van/BI-4 - NAFEC system located at Bader Field, Atlantic City and Newport, New Jersey.
5. Extended Area Instrumentation Radar (EAIR) - C-Band tracking radar used in the beacon tracking mode for primary position data.
6. Phototheodolites - a four-station optical tracking complex for accurately determining primary position data.
7. Range Control - provides real time to all test facilities and aircraft and provides communications to facilities and test aircraft.

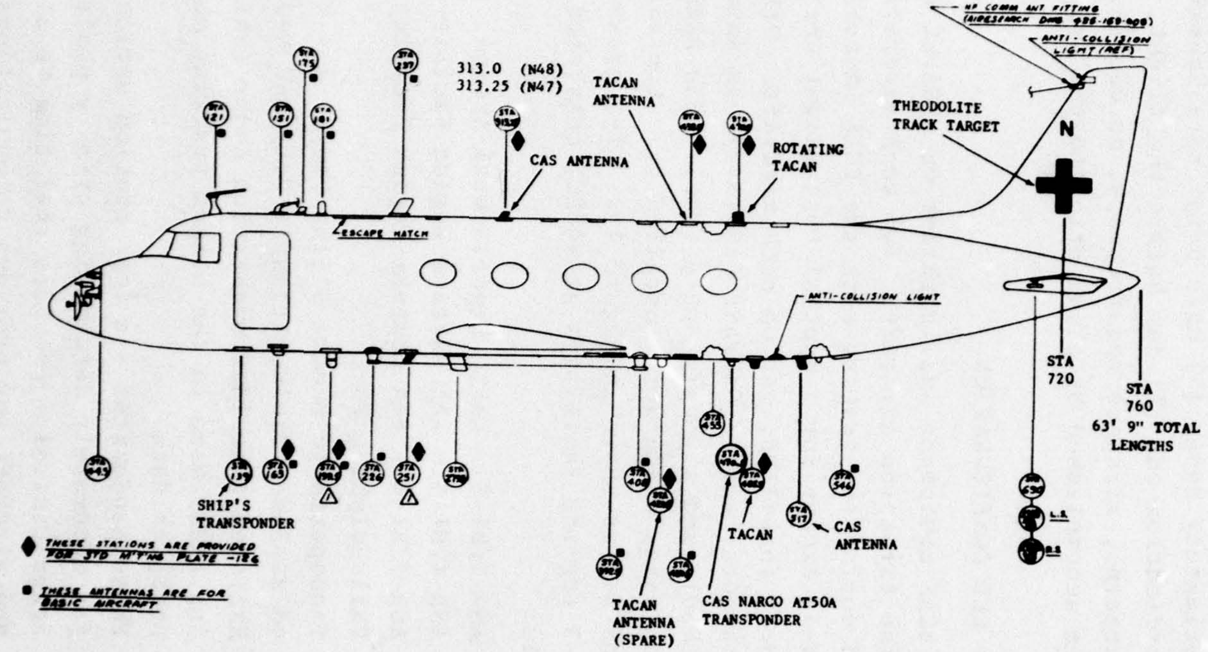


FIGURE 4-2. BCAS ANTENNA LOCATIONS ON N47 and N48

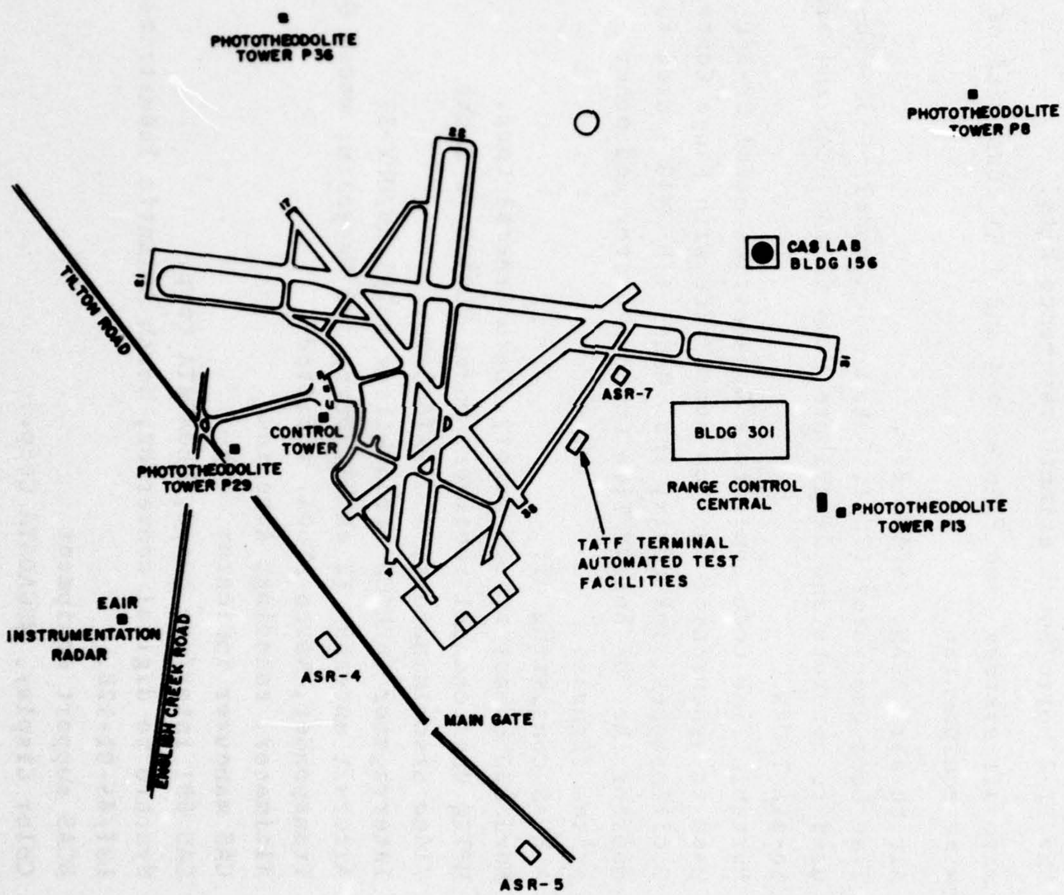


FIGURE 4-3. NAFEC BCAS TEST FACILITIES

8. ARTS III, NAFEC, Terminal Automated Test Facilities (TATF) used for multiaircraft tracking and ATCRBS environmental studies.
9. ARTS III, Philadelphia, PA - used for multiaircraft tracking and ATCRBS environmental studies.
10. Reference transponder, Mizpah, New Jersey - RT-859/APX-72.
11. ASR-7/BI-4, NAFEC experimental radar - used to check out the BI-4 North/South azimuth reference kits.

The aircraft systems (see Figures 4-4 and 4-5) consisted of the following equipments:

1. Air-to-air TACAN, AN/ARN-84V.
2. Time Code Generator (TCG), Datametrics model SP-305-SE- used to generate and distribute time to the BCAS and air-to-air TACAN.
3. Portable Time Code Generator, Datametrics model SP-380- used to synchronize the "on board" TCG with Range Control.
4. Oscilloscopes, Tektronix, Inc. Model 475 DM40 - used to monitor the "on board" Time Code Generator and other system signals.
5. A BCAS consisting of:
   Nova 800 computer, 32K memory, Data General Corp.
   MITEQ dual channel receiver, model RL8400 (2 each)
   Video discriminators, MEGADATA Corp.
   Interrogator CARDION (transmitter only) AW/UPX-27
   Aircraft antennas (2 each), Dorne and Margolin, model Q57
   Transponder, Narco AT50A, modified
   Altimeter, encoding, Aerosinc
   CAS maneuver indicator, GFE
   CAS 801 interface board, MEGADATA Corp.
   Synchro to digital converter, North Atlantic Industries, LSI/85-01-12B.
6. BCAS support equipment
   Color display, MEGADATA Corp.
   CAS 802 interface board, MEGADATA Corp.
   Monochrone display, MEGADATA Corp.

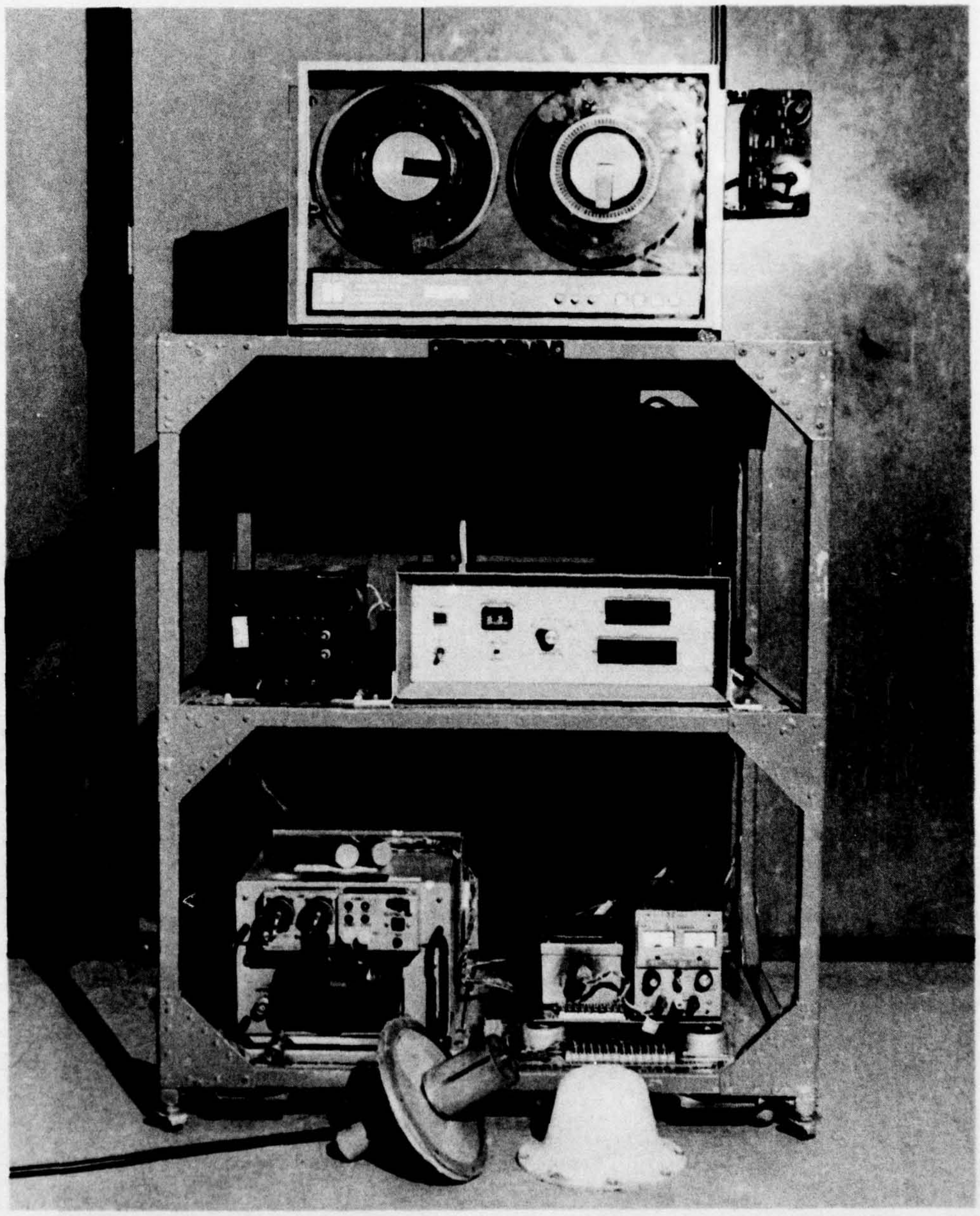


FIGURE 4-4. GULFSTREAM N47 TACAN AIR-AIR RANGE MEASUREMENT INSTALLATION AND TIME CODE GENERATOR

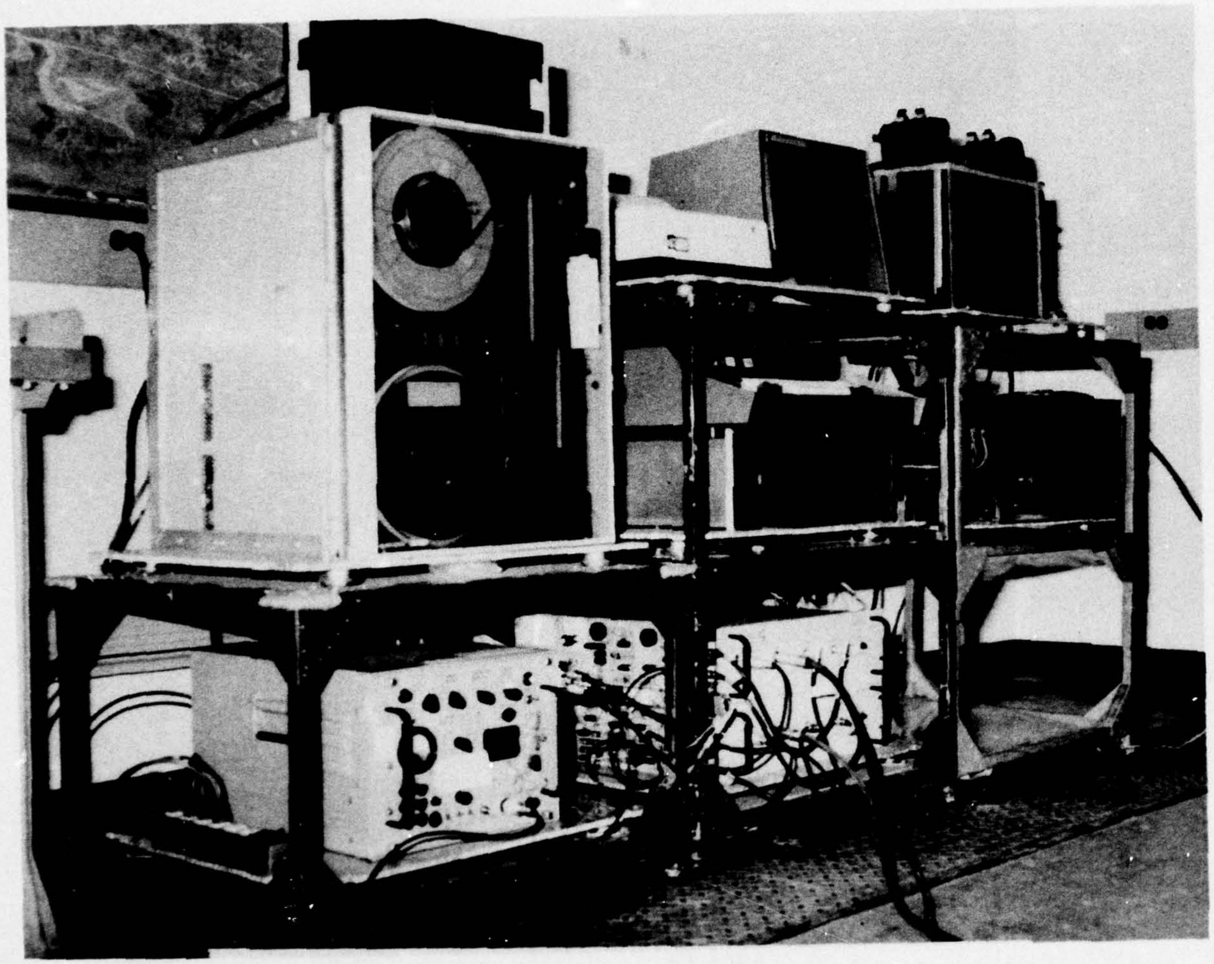


FIGURE 4-5. EXPERIMENTAL BCAS SYSTEM

Display Controller (Color), MEGADATA Corp.
Mag tape recording system, DATA General Corp., Model 6021
Paper tape reader, DATA General Corp., Model 6013
Paper tape punch, DATA General Corp., Model 4012A
Printer, EXTEL, Model AH11R
Monochrome display controller/keyboard, MEGADATA Corp.
Second Monochrome Display, MEGADATA Corp.

The BCAS interfaced with the following systems:

1. The aircraft heading synchro was interfaced through the contractor's synchro-to-digital converter to the BCAS computer.
2. The barometric pressure system was interfaced with the contractor's Aerosinc encoding altimeter.
3. The output of the Time Code Generator was interfaced with the BCAS computer (Figure 4-6).

4.3 FLIGHT TEST PATTERNS

A set of 15 basic flight test patterns were designed to satisfy the test requirements and aircraft capabilities. These patterns are shown in Appendix B and consist of figure eights, rotating double-daisies, curved path encounters, etc. These patterns were used not only for the formal test flights, but also for the contractor's debugging flights.

In the course of the test program, it was necessary to modify the test patterns to accommodate changing test requirements, airspace problems, weather conditions, test bed equipment availability, etc.

4.4 FLIGHT TEST PROCEDURES AND CONDUCT

The following is a brief scenario of the flight test designed to collect BCAS Performance Data, illustrating test procedures and conduct. The flight test or mission involved a series of two aircraft encounters over the Millville VOR. The purpose of the test was to gather encounter performance data of the BCAS system while it was operating in both the passive and active mode.

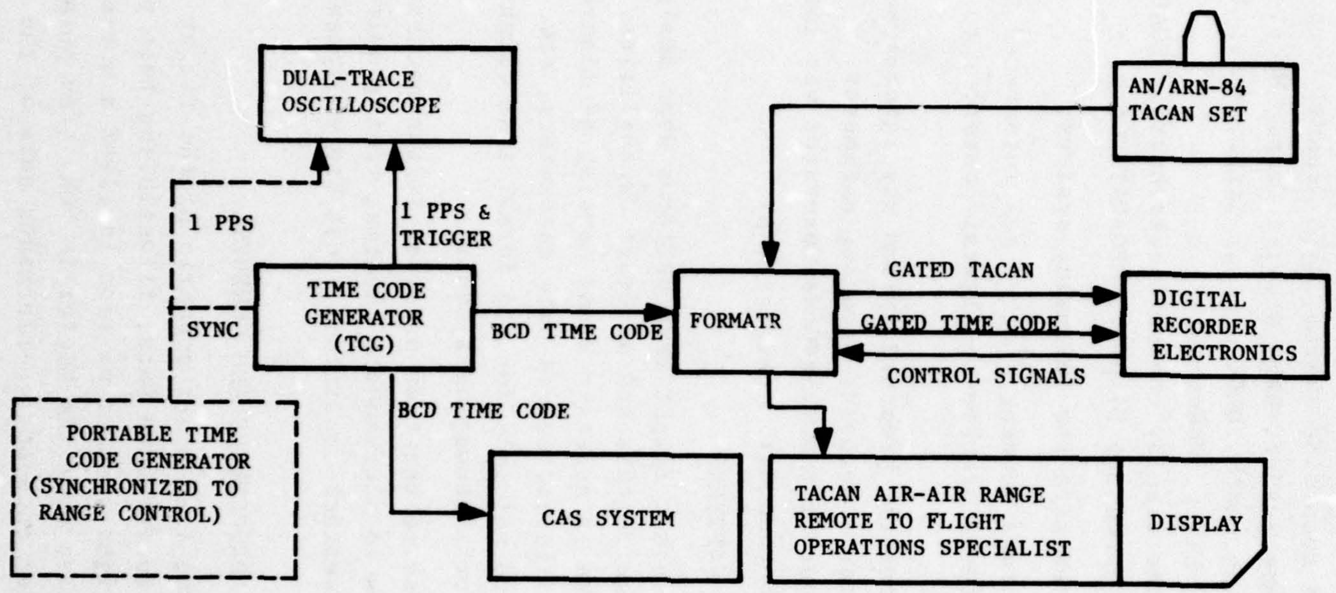


FIGURE 4-6. BLOCK DIAGRAM OF TIME CODE GENERATING SYSTEM AND TACAN AIR/AIR RANGE MEASUREMENT SYSTEM

Prior to the start of the overall test program, it was established that three test days a week with morning and afternoon flights would be scheduled. The facility and airspace requirements for each mission were reviewed and tentative test periods assigned. This was, in part, necessary because of the long lead time needed in scheduling some facilities and for coordination of airspace.

The mission test plans were reviewed again in detail before the scheduled test period at a preflight meeting.

Items that were discussed included:

1. Purpose of test.
2. Personnel assignments.
3. Communication procedures and frequencies.
4. Test pattern(s).
5. Time synchronization procedure.
6. Test log recording procedures.
7. Data recording procedures and requirements.
8. Beacon codes to be used.
9. Aircraft status.
10. Weather forecast.
11. BCAS operation.
12. Transponder calibration.
13. Status of all facilities to be used.
14. Data tape collection and processing.
15. Tracking system requirements.

Alternate missions and procedures were established in the event of problems in airspace allocation, weather conditions, system failures, etc. This planning proved to be very important because of the weather and the number of people and facilities involved and the limited control that existed over some of the resources. Weather was probably the greatest problem, as it impacted our VFR requirement and the availability of operational facilities and airspace.

For this sample mission, three beacon sites were needed: the Philadelphia ASR-7, the NAFEC ASR-5 and the Newport van. People were assigned to the NAFEC and Newport sites and given logs to

record certain parameters (such as power, mode interlace, etc.) and also to monitor the N/S azimuth reference pulse. At Philadelphia, this was done by the Eastern Region technicians and coordinated by phone.

Data was to be recorded at the Philadelphia and NAFEC ARTS III facilities. Air Traffic Controllers from NAFEC were assigned to the terminal control facility to assist in recording the necessary data, coordinate the airspace usage, and to keep a data log. Coordination for use of the facilities on each particular day had been made earlier.

Communications were organized as shown in Figure 4-7. Three radio channels were assigned: VHF# 1 for air-to-ground Air Traffic Control, VHF#2 for air-to-air and air-to-ground for test personnel, UHF# 1 for cockpit to cockpit flight crew coordination. Special phone lines, accessible from the ARTS III (NAFEC), were installed at the Philadelphia ASR-7 site and approach control, and the portable beacon siting van. Phone communications from ARTS III were also available to EAIR, ASR-5, ASR-4, Range Control, CAD and the beacon van.

Time synchronization was to be accomplished in the following manner:

> A portable Time Code Generator was synchronized before each flight to real time at the Range Control facility and then transported to the test aircraft. The "on board" Time Code Generator was then synchronized to it. This system reference time was remoted to the TATF and EAIR by Range Control. At the TATF, time was entered into the system via the data entry keyboard from the remote digital time display. A time check was made with the Philadelphia ARTS III via phone and the time difference, if any, was recorded. When all systems were operating, another time check was made.

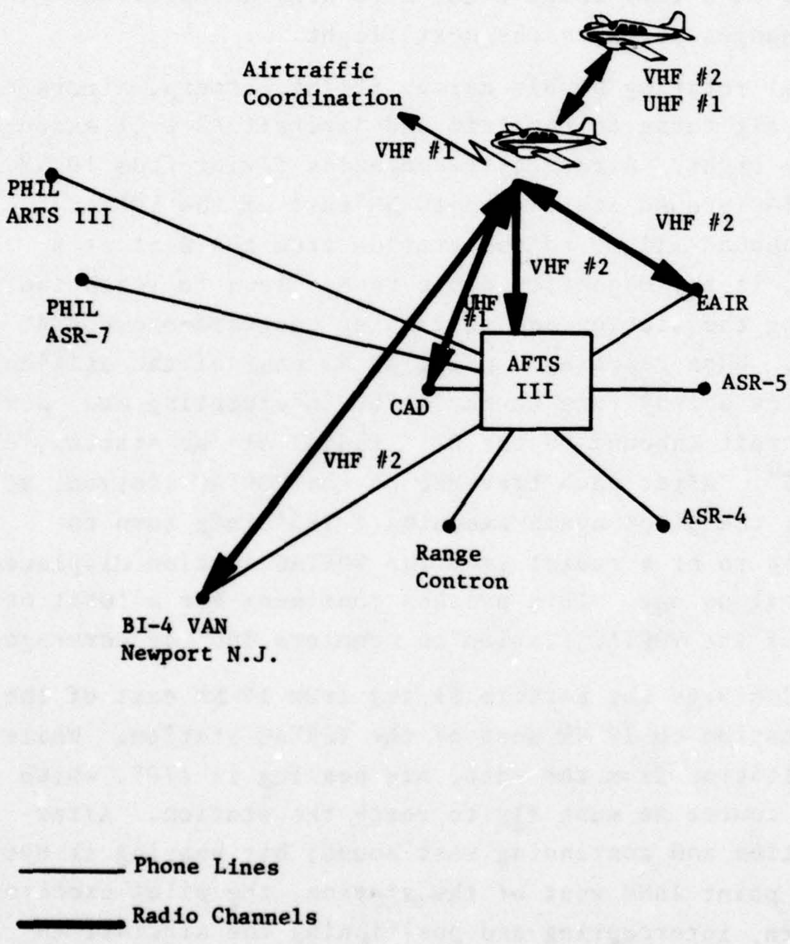


FIGURE 4-7. VOICE COMMUNICATION LINKS

The flight test pattern and procedures were finalized. Pattern #10 of Appendix A, a two aircraft modified or rotating double daisy pattern was used. Encounters 1 through 12 were at the high altitude and encounters 13 through 24 at the lower altitude.

Data acquisition performance was verified using a modified or rotating double daisy which presents 360° of coverage in 12 runs, with encounters 30° apart. This allows acquisition of data for 360° of coverage in a very short time, affording an opportunity for necessary changes prior to the next flight.

In a typical rotating double daisy flight pattern, Aircraft #1 will execute all turns to the left and Aircraft #2 will execute all turns to the right. Aircraft #1 commences flying from 10 NM west of the VORTAC ground station to 10 NM east of the VORTAC station. The inbound flight to the station from the west at a bearing of 090°, is the magnetic course to be flown to reach the station. Passing the station and continuing eastward the VORTAC bearing is 270°. Upon reaching a point 10 NM east of the station, the pilot executes a 195° turn to the left, intercepting and positioning the aircraft inbound on the 075° radial of the station, or a bearing of 255°. After each traverse of the VORTAC station, at the 10 NM point, the pilot again executes a 195° left turn to acquire a bearing to or a radial from the VORTAC station displaced 15° from the previous one. This process continues for a total of 12 transverses of the VORTAC station to complete 360° of coverage.

Aircraft #2 starts the pattern flying from 10 NM east of the VORTAC ground station to 10 NM west of the VORTAC station. While inbound to the station from the east, his bearing is 270°, which is the magnetic course he must fly to reach the station. After passing the station and continuing west bound, his bearing is 090°. Upon reaching a point 10NM west of the station, the pilot executes a 195° right turn, intercepting and positioning the aircraft inbound on the 285° radial of the station, or a bearing of 105°. After each traverse of the station, at the 10 NM point, the pilot again executes a 195° turn to acquire a bearing to or a radial from the VORTAC station displaced 15° from the previous

one. This process, as that of aircraft #1, continues for a total of 12 traverses of the VORTAC station to complete 360° of coverage (Table 4-1, Figure 4-8).

Usually this pattern requires both aircraft to maintain a constant airspeed, normally 150Knts, with 400 feet of vertical separation. The exceptions are runs numbered 7 and 19, which are tail-chase runs. During a tail-chase, aircraft #2 will increase speed to 230Knts and start the turn-in at a point 14.3 NM from the station instead of 10 NM. Aircraft #1 is designated as the control aircraft and calls each mile mark during each run. This allows Aircraft #2 to adjust speed so as to expect crossovers directly over the VORTAC station.

As shown in Table 4-1, this pattern provides positive and negative intercept angles throughout a 360° azimuth area in 30° increments.

After the preflight meeting, a briefing was held with the flight test pilots and crews and the following items were resolved:

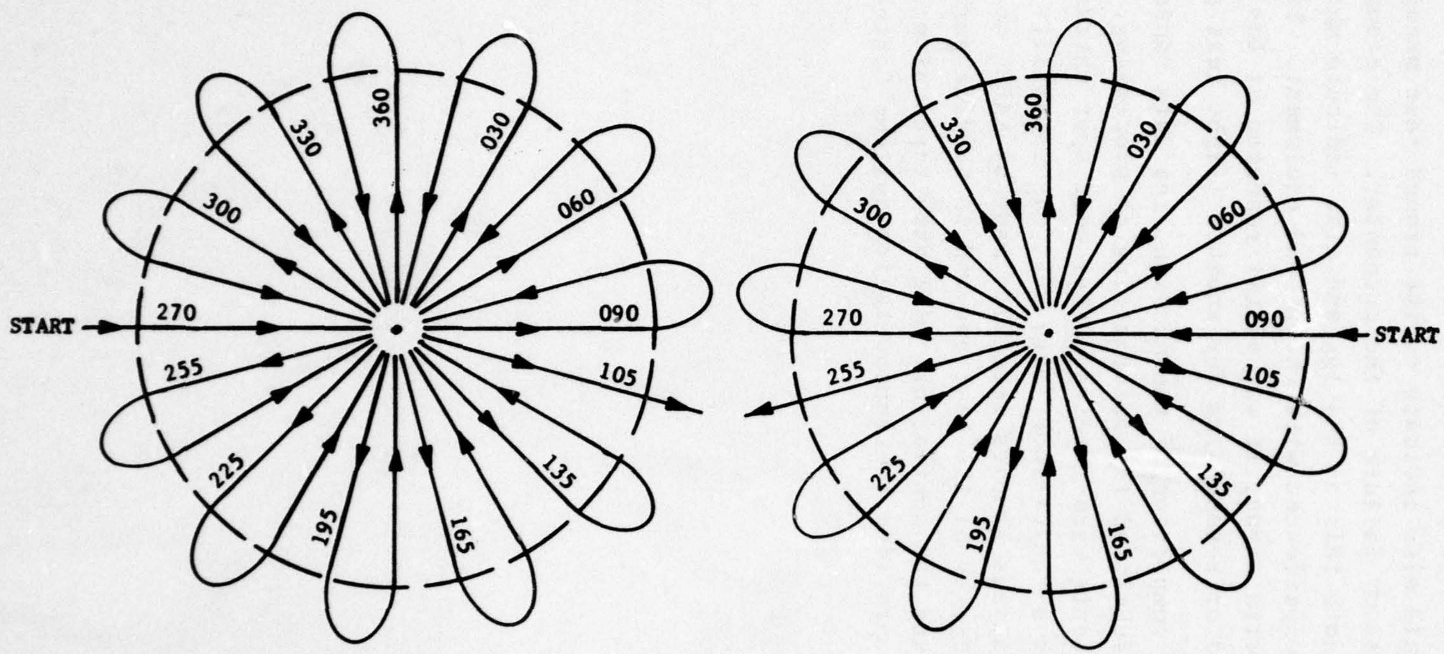
Aircraft/crew manifest
Block time/flight duration/fuel load
Lead aircraft/#2/#3, taxi and T/O sequence
Pattern and position procedure
Altitudes/air speeds/distance calls
Run sequence list
Communications (A/G, A/A, ATC)
Transponder settings (front/rear)
Tracking requirements
Weather
Flight plan remarks (formations, waivers, etc.)
ATC coordination
Special remarks.

Immediately prior to test time the status of all equipment was ascertained and communication links checked out.

When the aircraft were in position to start the pattern, the flight test manager aboard the control plane would "call out" the start of run or encounter. He would then proceed to mark the

TABLE 4-1. ANGLE ASSIGNMENTS FOR DAISY PATTERN

#NO. ENCOUNTER	HDG. A/C #1	HDG. A/C #2	INTRCPT ANGLE
1	090	270	180
2	255	105	150
3	060	300	120
4	225	135	90
5	030	330	60
6	195	165	30
7	360	360	0
8	165	195	30
9	330	030	60
10	135	225	90
11	300	060	120
12	105	255	150
13	270	090	180
14	075	285	150
15	240	120	120
16	045	315	90
17	210	150	60
18	015	345	30
19	180	180	0
20	345	015	30
21	150	210	60
22	315	045	90
23	120	240	120
24	285	075	150



A/C #1, LEFT TURNS.
ENCOUNTERS 1 THRU 12.
ENCOUNTERS 13 THRU 24
OPPOSITE DIRECTION OF
ARROWS.

A/C #2, RIGHT TURNS.
ENCOUNTERS 1 THRU 12.
ENCOUNTERS 13 THRU 24
OPPOSITE DIRECTION OF
ARROWS.

FIGURE 4-8. ROTATING OR MODIFIED DOUBLE DAISY PATTERN

crossover time and stop time (data was not to be recorded during turns). He would also indicate to the ground test manager the apparent success or failure of the encounter. The ground test manager would note this on his log and also indicate whether any problems were experienced with the ground equipment. If there was a problem with a run, it was either repeated at the end of the test period or rescheduled for another flight test period.

After the completion of the mission, the data tapes were collected and submitted for reformatting or processing. When the data tape printouts were received, they were spot checked for gross anomalies using a "quick-look" data analysis capability at NAFEC. Post-flight analysis studies were also made at NAFEC to assure the continuing integrity of the test bed and to provide performance status to TSC and the contractor. All data tapes after preliminary screening were provided to Transportation Systems Center (TSC).

5. FLIGHT TEST DATA ANALYSIS

5.1 FLIGHT TEST RESULTS

A summary of measured and derived experimentally BCAS performance values is presented in Table 5-1. Detailed analyses are given in the references to this report.

TABLE 5-1. EXPERIMENTAL BCAS ACCURACY

Parameter	RMS Error	Comments
Directly measured:		
TOA	.15 μsec	Measured against the EAIR precision C-Band tracking radar and a fixed target as other.
DAZ	.30 degrees	
OAZ	.25 degrees	
Derived:		
θ	.3 degrees	
r	300 feet	

The accuracy of the BCAS measurements was assessed by measuring TOA's and DAZ's during a series of flights past the fixed transponder and simultaneously tracking the BCAS aircraft with the EAIR precision radar, as well as with the ARTS III system. The TOA and DAZ values measured by BCAS were then compared with predicted values based on the geometric relationship of the radar, target transponder (determined by survey) and BCAS position (measured by the EAIR radar). The mean values of the differences were attributed to system bias. The variance of the difference between measured and predicted values is considered to be due to random errors of measurement.

The measured values of TOA, DAZ, and OAZ were also used to compute the range and bearing to the target by solving equations 3.2.1 - 3.2.3.

The computed values were compared to the values derived from the EAIR radar measurements. In addition, an extensive set of simulations were run to examine the effect of measurement errors on the computed range and bearing errors in a wider range of configurations than could reasonably be test flown. The sensitivity of range and bearing accuracy to measurement errors does depend in a complex way on the radar and aircraft configuration.

The values in Table 5-1 are representative of configurations with radars about 20 miles from the aircraft, which are some 3 miles apart. There are, however, rather sharply defined configurations when the BCAS and the target aircraft are approximately colinear with the radar in which satisfactory values of range and bearing to the target cannot be computed from the measurements. In such cases, the BCAS must, where possible, select a different SSR for tracking that target or use its on-board interrogator.

Test flights were flown to determine the maximum range at which BCAS could utilize a given SSR. The relevant parameters continuously observed were the quality of radar lock (SLS pulses detected/total number of SLS pulses per scan), number of main beam interrogation detected per scan, and number of P_N pulses detected per scan.

Flight tests were also conducted to establish if either the P_N pulses emitted by the SSR's or the active interrogations by the BCAS were creating any interference with normal ATC surveillance radars. Analysis of the data showed no interference with ATC operation. A summary of measured BCAS characteristics is shown in Table 5-2.

5.2 RANGE - BEARING EVALUATION

The measurements made by the BCAS system - the bearing to at least two ground radars, the differential azimuths to a potential threat, and the TOA's of the transponder signals from the threat - are sufficient to calculate the range and bearing to the threat from the BCAS aircraft. Currently these calculations are not being performed in flight, but sufficient data are gathered to

TABLE 5-2. EXPERIMENTAL BCAS CHARACTERISTICS

Parameter	Measured Values
Number of Targets Tracked	9
Number of Radar Locks	3
Range to SSR (max.)	100 nmi
SLS Rec. - 90dbm	
MB Rec. - 65dbm	
Range to Target (max.)	
Receiver - 85dbm	8 nmi
Probability of Detection	See Note

NOTE: The data analyzed showed that all targets within the coverage region detected by ARTS were also detected by BCAS. For some aircraft, both ARTS and BCAS formed multiple tracks. However, the derived position of these tracks, when compared, did not agree.

allow them to be performed afterwards. An algorithm was developed to compute range and bearing from the data collected in flight using off-line computers. This program was developed by TSC, and implemented in FORTRAN for the PDP-10 computer. It is identified as NUPAS. A detailed discussion of this algorithm is given in Appendix D.

The new algorithm was tested in a set of simulations to evaluate its performance with perfect measurement data and with measurement data corrupted with known errors. The following was established:

1. When the algorithm operates with perfect input data (i.e., perfectly accurate TOA and azimuth data corresponding to the position of the radars and the aircraft) it produces perfect solutions for the range and bearing of the threat aircraft with respect to our own (BCAS). The principal exceptions, whose causes are understood and discussed in Appendix D, occur either when the intruder aircraft is in a region between one of the surveillance

radars and the BCAS aircraft or when the BCAS aircraft is between the intruder and the surveillance radar. The algorithm is an iterative one, but convergence is very fast. In two iterations, the "noise-free" solutions were found to be accurate to within one foot in range and .01 degrees in bearing.

2. The solutions are not unduly sensitive to measurement errors. A limited set of simulations were performed in which known fixed errors were added to the "perfect" input values described above. The errors were of the approximate magnitude of the RMS measurement errors. The precise effects depend very much on the specific configuration of radars and aircraft, so that average values of the error effects are not in themselves meaningful. In general, DAZ measurement errors may affect the answers more than TOA errors. In all but the unfavorable geometries the effects of the simulated input errors ($\pm.27\mu$ sec in TOA, $\pm.15°$ in AZ and DAZ, ±75 feet in H) resulted in computed positions of others within 200 feet of the nominal location. The rate of convergence was not significantly affected by the presence of the errors.

The algorithm was also applied to calculating separations between the two aircraft involved in the flight tests of October 15, 1976 using the actual data gathered on those flights. The flights were encounters flown in the Milville area using the "rotating daisy" pattern. The BCAS was locking to the NAFEC ASR-4 and Philadelphia terminal radars. Reply data received by the ARTS III system at NAFEC was recorded.

The TOA, OAZ, and DAZ data for three of the flights are shown in Figures 5.2-1-5.2-9.* The slant range between the aircraft and the computed bearing from the BCAS aircraft to the target are plotted in Figures 5.2-10 - 5.2-19. The slant range and bearing derived from the ARTS measurements are plotted in the same figures for comparison. Also, extrapolated data using the two second update interval instead of the normal antenna scan rate of 4 seconds are also presented in Figures 5.2-10a and 5.2-12a for comparison. The smoothed data provide better results as evidenced from the graphs.

*All figures and tables identified by 3-digit numbers are located in Appendix F.

The on-board interrogator controlled by the computer sends out active mode interrogation sequences consisting of 12 top antenna and 12 bottom antenna interrogations with a 30 microsecond switch-over time between these interrogations.

The data from the active interrogator were not used in calculating the threat range and bearing by the NUPAS algorithm. However, since the replies to the on-board interrogator give a good measure of slant range to the target, the slant range derived from them is also shown on the plots for comparison with the other values obtained for range.

On the plots of separation distance, the values derived from the active interrogations are indicated by circles. They are shown for every value of time at which an active interrogation burst received a target report.

The values of slant range and bearing computed from the ARTS data are shown at the time of the ASR-4 main beam passage past the BCAS aircraft every time that valid target reports were received from both the BCAS and the target aircraft during one antenna rotation period. The values are indicated as short horizontal lines crossing vertical lines which represent the (approximate) 90% confidence intervals for these quantities. The derivation and significance of these error bars are discussed in Appendix G.

The slant range and bearing to the target computed by NUPAS, i.e., the BCAS computed positions of the threat aircraft, are shown in the figures as small x's or inverted v's. The inverted v's are used when the configuration of the aircraft relative to the radars is such that the available pair of radars does not meet the criteria of a "good" radar pair as currently defined within NUPAS. The x's are used otherwise. It may be observed that the criteria for "good" radar pairs are evidently more stringent than they need be, since the range and bearing calculations do not appear to be noticeably worse when the radar pair does not satisfy them.

The range and bearing to other are computed for every instant of time for which a target report is received - i.e., at the time of main beam passage of either of the locked radars. No filtering,

smoothing or extrapolation of any kind is performed on the measured values except for Figures 5.2-10a to 5.2-12a of the differential azimuth and TOA. Each calculation is based on the values of own azimuth, differential azimuth, and TOA just obtained for one radar at the instant for which range and separation are computed and on the most recent values of these parameters obtained for the other locked radar. The values from the other radar are those of an observation at some instant in the past, descriptive of the aircraft positions at the earlier instant. Values older than 10 seconds were never used. In general, unless there was a radar rotation period during which no target report was obtained by the BCAS system for the target being tracked, the calculation was based on a pair of target reports separated in time by between 0 and some 4 seconds (one radar rotation period).

The relation between the aircraft configurations, the BCAS system measurements, and the calculations based upon them is extremely complex. There is no simple way to express the effect of this time difference in the observations. It may be noted in the figures that there are instances when two range and bearing solutions are given close together in time. Then the earlier is based upon the measurements based on radar A at that instant and the measurements based on radar B made almost a full antenna rotation period previously. The latter is based upon the newly updated radar B measurements and the radar A measurements made at the earlier instant - i.e., upon a set of measurements made close together in time.

It may be observed that the values at the second instant tend to be better - i.e., closer to the presumably correct value that may be deduced by considering the general trend of the data and the ARTS and active radar measurements. On the other hand, the errors due to the time interval between observations are never very large.

Computed range and bearing values for good geometries are on average 300 feet rms and .3 degrees rms respectfully. Some improvements in these values are expected from better data smoothing and extrapolation. It may be observed that the passive BCAS could not

follow the threat aircraft at the time of the closest approach during the encounters flown, but that the ARTS system could not do so either. The active system could track threat range continuously.

Prior to November 19, 1976 there was an error in the BCAS own azimuth computation program which resulted in large transient oscillations in recorded "own azimuth" whenever radar lock was newly acquired. This has now been corrected. Unfortunately the effects of this error tend to appear frequently in the data for flights involving the "rotating daisy" flight patterns. The aircraft tend to bank sharply and lose radar lock at the ends of the petals. Radar reacquisition occurs near the beginning of the encounter run, and the transient in the azimuth value does not die out for several minutes. The nature of the transient is seen in Figure 5.5-1 to 8 and the effects on the computed range and bearing in Figures 5.2-12, 5.2-15, 5.2-18 and 5.2-19.

5.3 TOA MEASUREMENT ACCURACY

The accuracy of the BCAS TOA measurements was assessed by comparing the TOA's measured during a series of flights past the fixed transponder in the Mizpah fire tower with values of the TOA's predicted from the relative positions of the BCAS aircraft and the fire tower. These positions were simultaneously obtained by the NAFEC ARTS III system and the EAIR tracking radar system. The ARTS system measured both the aircraft and the tower transponder positions once every rotation period. It may be noted that the BCAS system measured the TOA of the transponder signals that were identically the same as those that the ARTS III system used to establish the transponder location. The EAIR system tracked the aircraft only. The position of the tower used in predicting the TOA's (and the differential azimuths of Sections 5.2.3) was the surveyed position. The results of the tests are given in Table 5.3-1 (Appendix F, supporting data) and Figures 5.3-1 - 5.3-8.

TABLE 5-3. DIFFERENCES BETWEEN TOA'S MEASURED BY BCAS AND PREDICTED FROM GROUND SYSTEM MEASUREMENTS

RUN	ARTS III			EAIR		
Number	Number of Samples	Sample Mean (Sec.)	Sample Std. Dev.	Number of Samples	Sample Mean (Sec.)	Sample Std. Dev.
2	13	-.390	.865	-	-	-
3	62	-.016	1.336	78	.034	.121
4	26	-.225	.926	33	.418	.084
5	69	.649	1.676	88	.295	.098
6	38	.352	.480	43	.393	.137
7	56	-.378	.415	75	.308	.093
8	17	-.320	1.012	35	.340	.116
9	21	-.106	.772	59	.274	.088
10	10	.934	2.570	24	.382	.071
11	69	-.397	.282	83	.325	.105
TOTAL	381		1.154	518	.341	.113

There is an average difference of 0.341 microseconds between the measured TOA's and the TOA's predicted on the basis of EAIR measurements, but the RMS variation (i.e., the standard deviation) of this observed difference is only 0.113 microseconds. Since the EAIR and the BCAS systems are totally independent, this implies that there is some systematic bias in arriving at the value of the TOA in at least one of the systems, but that the random variation in the measurements is quite small. It may be noted that within the BCAS system, TOA is quantized to intervals of 0.145 microseconds. This quantization by itself introduces a random RMS error of about 0.05 microseconds. Since there is also some random variation in the EAIR measurements which contributes to the random element in the calculated TOA differences, it may be concluded that the RMS value of the random variation in the measured TOA's due to factors other than quantization noise is less than 0.1 microseconds.

Comparing the measured TOA's with the TOA's computed from the ARTS III measurement, one does not observe any statistically significant mean difference between them (i.e., no system bias). However, the variance of the difference is quite large. The standard deviation (i.e., the RMS value of the random component) of the difference is seen to be 1.154 microseconds. Since no random fluctuation was found in the BCAS - measured TOA's when compared to the TOA's computed on the basis of the independent EAIR system measurements, it must be concluded that this variation is in the ARTS measurements alone.

The measurements analyzed here were made for TOA's of signals from a stationary transponder to a moving BCAS aircraft. TOA's from a moving target to a moving BCAS system are plotted in Figures 5.2-1, 5.2-4 and 5.2-7. Quantitative measures of accuracy have not been computed, since the EAIR system cannot be used to track two aircraft simultaneously and since the values derived from ARTS measurements themselves appear to be significantly less accurate than the BCAS measurements. However, inspection of the figures indicates that the accuracies are comparable to those for the stationary target.

The measurements taken initially with a fixed target were repeated on January 6, 7, 1977 when all improvements had been incorporated in the BCAS software. These results are shown in Table 5.3-1 and Figures 5.3-9 - 5.3-18 and are considered as representative for assessing TOA measurement accuracy.

TABLE 5-4. TOA DIFFERENCES IN MICROSECONDS BETWEEN BCAS MEASUREMENTS AND VALUES PREDICTED ON THE BASIS OF EAIR MEASUREMENTS

Run #	N	m	s^2
Outbound			
1	53	.238	.042
5	58	.220	.024
9	59	.240	.027
(1,5,9)	150	.233	.030
Inbound			
2	58	.169	.018
6	55	.197	.012
10	63	.209	.017
(2,6,10)	176	.192	.016

N = number of samples in set
m = sample mean of data in set
s^2= sample variance of data in set

5.4 DIFFERENTIAL AZIMUTH ACCURACY

The accuracy of the BCAS measurements of differential azimuth was evaluated on the basis of the data gathered on the same test flights past the Mizpah fire tower on November 9, 1976 as were used for evaluating TOA measurement accuracy. The results of the test are presented in Table 5-5 and Figures 5.4-1 - 5.4-8. It is seen that the mean difference between the BCAS computed

TABLE 5-5. DIFFERENCES BETWEEN DIFFERENTIAL AZIMUTH MEASURED BY BCAS AND PREDICTED FROM GROUND SYSTEM MEASUREMENTS

RUN	ARTS III			EAIR		
Number	Number of Samples	Sample Mean (degrees)	Sample Std. Dev.	Number of Samples	Sample Mean (degrees)	Sample Std. Dev.
2	13	.019	.275	-	-	-
3	62	-.212	.398	78	-.213	.403
4	26	-.210	.471	33	-.098	.254
5	69	-.061	.293	88	-.053	.354
6	38	-.206	.391	43	-.092	.223
7	56	-.044	.428	75	-.064	.374
8	17	.051	.433	35	.006	.387
9	21	.157	.547	59	.214	.492
10	10	-.145	.462	24	.005	.506
11	69	-.209	.356	83	-.152	.193
TOTAL	381	-.117	.403	518	-.0676	.362

AD-A058 936 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 1/4
EXPERIMENTAL BCAS PERFORMANCE RESULTS.(U)
JUL 78 J VILCANS, E QUISH, J G RAUDSEPS
UNCLASSIFIED TSC-FAA-78-9 FAA-RD-78-53 NL

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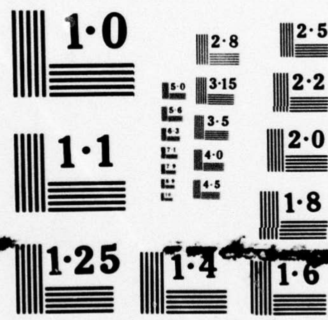

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differential azimuth and the DAZ calculated from EAIR data is 0.07 degrees, and the sample standard deviation is 0.36 degrees. The mean difference between BCAS and ARTS values is 0.12 degrees, with a standard deviation of 0.40 degrees. See Table 5-6 for supporting data.

TABLE 5-6. DIFFERENTIAL AZIMUTH IN DEGREES BETWEEN BCAS MEASUREMENTS AND VALUES PREDICTED ON THE BASIS OF EAIR MEASUREMENTS

JTIDS Off

Run #	N	m	s^2
Outbound			
1	53	-.061	.157
5	58	-.125	.077
9	59	-.065	.129
(1,5,9)	170	-.084	.119
Inbound			
2	58	-.107	.111
6	55	-.101	.079
10	63	-.168	.114
(2,6,10)	176	-.127	.102

N = number of samples in set
m = sample mean
s^2= sample variance

Analysis performed at TSC showed that DAZ computations could be in error up to 0.87 degrees. In performing the computations, the BCAS software utilizes only the most significant half of the double length interrogation time. Thus up to 9.5 ms may be truncated from the computations, which for the ASR-4 (scan period: 3.934 seconds) radar would result in such stated errors.

Quantization noise of this magnitude introduces random error with an RMS value of about .3 degrees.

Since the differential azimuth is determined by calculating the difference between the centroids of two groups of transponder replies to ATCRBS interrogator pulses that are emitted approximately every 0.1 degree of antenna rotation, it is seen that the BCAS accuracy achieved is close to the theoretic optimum. It may be noted that ARTS III RMS error in measuring differential azimuth is about .4 degrees (See Appendix E.)

The calculated mean and RMS differences given in Table 5-5 apply to the case of a moving BCAS system measuring its differential azimuth with respect to a stationary target.

Comparison with Figures 5.2-3, 5.2-6 and 5.2-9 shows that essentially the same results are obtained when both the BCAS system and the target are moving.

DAZ measurements were repeated with all software modifications incorporated and are shown in Table 5-6 and Figures 5.2-9 - 5.2-18.

5.5 OWN AZIMUTH

The BCAS software used to smooth the own azimuth measurements contained an error which was not found and corrected until November 19, 1976. The error had several effects. The filtered (smoothed) value of own azimuth, if it converged at all, contained a large transient (a damped oscillation) which started at the time of radar lock and decayed over a period of several minutes, reaching peaks of more than 20 degrees. (See Figures 5.5-1 -- 5.5-8.)

Even after the transient had decayed, there remained a constant offset of some 3 degrees between the true and the calculated values of own azimuth.

The software error giving rise to this problem has now been corrected. Figures 5.5-9 and 5.5-10 show comparisons of own azimuth values computed by BCAS (with the corrected program) and derived from EAIR measurements.

It is seen that there is essentially no error left in the own azimuth computations in the steady state. It remains to be verified that the transient error following upon radar lock-up has also been removed.

5.6 RECEIVER SENSITIVITY MEASUREMENTS

In order to determine the maximum effective range at which SLS pulses and main beam pulses can be received without breaking the radar lock, the following parameters were measured.

1. $\frac{\text{SLS hits x 100}}{\text{Total No. of SLS}}$ = quality of radar lock in %
2. Main beam hits
3. Number of uncorrelated radars
4. Fruit number/scan
5. Radar Lock Details: coastings, firm lock, etc.
6. Azimuth measurement.

Three independent flight tests were conducted under the following conditions:

Date	Altitude (ft)	Rec. Sensitivity (dbm)	Range of Detection (n.mi.)
5/6/76	13.0K	-90 (SLS)	120nm outbound
		-60 to -70 (MB)	125nm inbound
12/8/76	18.8K	-90 (SLS)	100 nm (typical)
		-65 (MB)	
12/27/76	21.0K	-90 (SLS)	127 nm outbound
		-70 (MB)	118 nm (typical)
		-65 (MB)	100 nm 80% count good lock

Considering the overall performance, it appears that optimum receiver sensitivity for the BCAS would be -90dbm for the SLS pulses and -65dbm for the main beam pulses.

A convenient range of operation for the BCAS system would be from 10 to 100 n miles, based on the receiver sensitivity settings and 150 watts peak power level at the ground interrogation site. The SLS and North pulses radiated on the onmi pattern can be detected up to distances in excess of 150 n miles. However, the main beam interrogation pulses radiated with 21 db antenna gain are detected typically up to 120 n miles for the -65 dbm receiver threshold.

5.7 NORTH PULSE KIT INTERFERENCE

Tests were performed to assess the effects of the presence of the north pulse kit on the operation of the ARTS III radar system. The nature of the test was to operate the ASR-4 system at NAFEC for a period of 112 minutes, alternatively turning the north pulse kit on and off at one minute intervals.

Statistics on ARTS III performance were gathered during each such period. The quantities which were considered to be of most interest and which were used in the subsequent analyses were the number of replies per target per scan (number of hits) and the run length of the sequence of transponder replies receiver by the ARTS III radar.

The averages and standard deviations of both these quantities were computed in each interval. Adjacent intervals were paired, and comparisons were made within each pair between the interval with the bits on and off. It was found that the average number of hits was greater with the bit off in 35 of 56 cases. Also the average run length was greater in 35 of 56 cases (not, in general, the same cases). These results are significant at the 2.5% level, i.e, there is no more than 2.5% probability that they are due to chance alone. The size of the effect however, is small. The observed average decrease in both the run length and the number of hits was on the order of 0.1, which may be compared to run lengths and average numbers of hits on the order of 18, with standard deviations on the order of 3.

5.8 HIGH RATE OF ACTIVE INTERROGATION

Tests similar to the north pulse interference tests were conducted to assess the effects of active interrogation in aircraft upon ARTS performance. The BCAS interrogator operating at 300 interrogations/second was alternately turned on and off at 1 minute intervals. ARTS performance measures were compared in 18 pairs of adjacent intervals. The average number of hits with the interrogator on decreased in 14 of 18 cases. The average target run length decreased in 12 of 18 cases. These results are significant at the 2.5% and the 12.5% level, respectively. Again, the observed differences themselves were small, amounting to 0.36 in the average number of hits.

5.9 X & D_1 PULSE ANALYSIS

5.9.1 Background

Co-altitude threats in the semi-active Beacon Collision Avoidance System are handled by means of "tie-breaker logic". One subsystem of the BCAS equipment is a standard ATCRBS transponder which emits X and D_1 pulses within the Mode C and an X pulse within the Mode 3/A reply message upon command from the onboard BCAS central processor. These pulses (X and D_1) are currently not designed for use in ATCRBS and have been authorized for use for BCAS testing. The pulses shall determine the direction of a potential maneuver of the BCAS equipped aircraft. The presence of these pulses in Mode 3/A and Mode C replies indicates the direction of maneuvers as follows:

X_A	X_C	$D1_C$	
0	0	0	no threat
0	0	1	threat-fly straight and level
0	1	0	dive
1	1	1	climb
1	0	0	turn left
1	0	1	turn right

X_A	X_C	$D1_C$	
1	1	0	turn left and change altitude
1	1	1	turn right and change altitude.

5.9.2 Discussion

A reply analysis routine was implemented to process ARTS III Data Extraction Tapes for Mode C containing X and D_1 pulses and Mode 3/A replies containing the X pulse. Although operational ATCRBS transponders do not use these pulses, the frequency of their erroneous use due to possible garbling, reply interleave, fruit, and the like was deemed worthy of investigation. The program was implemented to accumulate pertinent Mode C and Mode 3/A X and D_1 pulse statistics, with the statistics being grouped in terms of ungarbled and garbled replies.

5.9.3 Analysis

Table 5-7 depicts four 10-second intervals of reply data. These data were collected during the March 24, 1976 ASR-5 North/South Pulse Kit Installation Test.

The summary report (see Table 5-7) lists for subsystem 1 or 2 (in this case, subsystem 1 is the ASR-5), the total number of replies received by ARTS III from the ASR-5 during the ten-second interval, Mode C statistics including the number of replies processed and the percentages of processed for each of the four combinations of X and D_1 pulses, and Mode 3/A statistics comprising the number of replies of this type processed. In this instance, since D_1 is permissible for beacon code only, the two corresponding percentages for the X pulses are depicted.

Table 5-7 shows the four combinations of the North/South Pulse and the Defruiter (DEF) as follows:

TABLE 5-7. SUBSYSTEM 1 (ASR-5)

RUN #1	RUN #2	RUN #3	RUN #4
2784 Total Number of Replies	2472	2350	2927
Mode C (774 Replies)	Mode C (723 Replies)	Mode C (774 Replies)	Mode C (960 Replies
Ungarbled Replies D1 X Percent 0 0 99.483 0 1 .129 1 0 .129 1 1 .258	Ungarbled Replies D1 X Percent 0 0 100.000 0 0 .000 1 0 .000 1 1 .000	Ungarbled Replies D1 X Percent 0 0 97.028 0 1 .000 1 0 2.972 1 1 .000	Ungarbled Replies D1 X Percent 0 0 95.417 0 1 .000 1 0 4.583 1 1 .000
Garbled Replies (0)	Garbled Replies (0)	Garbled Replies (0)	Garbled Replies (0)
Mode 3/A (2010 Replies)	Mode 3/A (1749 Replies)	Mode 3/A (1576 Replies)	Mode 3/A (1967 Replies)
Ungarbled Replies X Percent 0 99.602 1 .398	Ungarbled Replies X Percent 0 99.886 1 .114	Ungarbled Replies X Percent 0 99.937 1 .063	Ungarbled Replies X PERCENT 0 100.000 1 .000
Garbled Replies (0)	Garbled Replies (0)	Garbled Replies (0)	Garbled Replies (0)

RUN #	KIT	DEF	TMIN	TMAX
1	OFF	ON	11/17/50	11/18/00
2	ON	ON	11/18/10	11/18/20
3	OFF	OFF	11/23/00	11/23/10
4	ON	OFF	11/23/40	11/23/50

Runs 1 and 2 (i.e., with the defruiter ON) depict data that is representative of the ATCRBS environment as ATRS III sees it. As shown in these tables, percentages of D_1 and X pulses for ungarbled Mode C replies are 0.4% and 0%, respectively, with percentages of X pulses for ungarbled Mode 3/A being 4.0% and 0.1%, respectively.

Runs 3 and 4 (i.e., with the defruiter OFF) contain higher percentages of D_1 and X pulses usage then the first two tables. These data, perhaps may be more representative of the ATCRBS environment as the BCAS system sees it. Corresponding percentages for Mode C and Mode 3/A for these tables are 3.0% and 4.6%, and 0.1% and 0, respectively.

Table 5-8 depicts data that were collected during the May 12, ASR-7 North/South Pulse Kit Installation Test. Similarly, each run is a 10-second interval representing the four combinations of the Kit and the Defruiter states as follows:

RUN #	KIT	DEF.	TMIN	TMAX
5	ON	ON	10/16/00	10/16/10
6	OFF	ON	10/20/00	10/20/10
7	OFF	OFF	10/23/00	10/23/10
8	ON	OFF	10/25/00	10/25/10

Unlike the ASR-5 radar, the ASR-7 radar did receive garbled replies for the four combinations of tests comprising both Mode C and Mode 3/A replies. The associated statistics for X and D_1 pulses usage are substantially higher for the ASR-7 than they were for the ASR-5. This phenomena may be attributable to multipath associated with the ASR-7 site.

TABLE 5-8. SUBSYSTEM 2 (ASR-7)

RUN #5	RUN #6	RUN #7	RUN #8
2180 Total Number of Replies	2304	10411	10840
Mode C (615 Replies)	Mode C (645 Replies)	Mode C (3388 Replies)	Mode C (3652 Replies)
Ungarbled Replies (595) D1 X Percent 0 0 98.824 0 1 .168 1 0 1.008 1 1 .000	Ungarbled Replies (618) D1 X Percent 0 0 100.000 0 1 .000 1 0 .000 1 1 .000	Ungarbled Replies (2713) D1 X Percent 0 0 83.856 0 1 1.696 1 0 13.085 1 1 1.364	Ungarbled Replies (2823) D1 X Percent 0 0 85.689 0 1 1.452 1 0 11.761 1 1 1.098
Garbled Replies (20) D1 X Percent 0 0 95.000 0 0 .000 1 0 5.000 1 1 .000	Garbled Replies (27) D1 X Percent 1 0 88.889 0 0 11.111 1 0 .000 1 1 .000	Garbled Replies (675) D1 X Percent 0 0 66.963 0 1 7.852 1 0 17.037 1 1 8.148	Garbled Replies (829) D1 X Percent 0 0 70.929 0 1 9.650 1 0 14.234 1 1 5.187
Mode 3/A (1565 Replies)	Mode 3/A (1659 Replies)	Mode 3/A 7023 Replies)	Mode 3/A (7188 Replies)
Ungarbled Replies (1495) X Percent 0 99.599 1 .401	Ungarbled Replies (1599) X Percent 0 99.875 1 .125	Ungarbled Replies (5573) X Percent 0 97.416 1 2.584	Ungarbled Replies (5571) X Percent 0. 86.841 1 3.159
Garbled Replies (70) X Percent 0 88.571 1 11.429	Garbled Replies (60) X Percent 0 75.000 1 25.000	Garbled Replies (1450) X Percent 0.84.483 1 15.517	Garbled Replies (1617) X Percent 0.86.889 1.13.111

5.9.4 Summary and Conclusions

Reply data from an operational ARTS III site were processed to calculate X and D_1 pulse utility. The X and D pulses were detected successfully except when two targets were close together. In such cases, ARTS III may associate the X and D bits with the replies from the wrong targets.

5.10 F2 TRACKING

5.10.1 Self-Garble Interference

When the BCAS aircraft is within the interrogating beam of an ATCRBS radar, the presence of a reply from its own on-board transponder will prevent BCAS receiver from properly receiving any transponder replies from other aircraft that might arrive at the BCAS before its own transponder has ceased transmitting. This condition is referred to as self-garble interference.

The BCAS receiver has been designed to receive replies partly obscured by self-garble interference. The technique employed is called F2 tracking. The principle of F2 tracking is the following: The OWN response may garble the first part of OTHER's received reply, but the later part of the reply will arrive clear. The reply can not be received in the ordinary manner because (a) the initial framing pulse (F1) is obscured by the self-garble and (b) because some of the code bits (pulses) may be obscured, so that the identity or altitude can not be properly decoded.

When the receiver is in the F2 tracking mode, the assumption is made that the beginning of a transponder reply from OTHER may have arrived at the BCAS receiver during the period that the OWN transponder was replying. Any pulse that arrives immediately after the conclusion of the own reply then is assumed to be the concluding part of such a reply. In particular, any pulse arriving during the 20.3 microseconds following the conclusion of the reply from the OWN transponder is assumed to be an F2 bracket pulse

concluding a reply whose first part, and specifically the F1 bracket pulse, was obscured. Therefore, an artificial F1 pulse is inserted into the detected bit stream 20.3 microseconds preceding the assumed F2 pulse. The subsequent reply detecting logic then detects two pulses at the proper bracket spacing and treats the combination of the presumed F2 pulse, the artificial F1 pulse, and any intervening pulses that may have been detected as a reply. The TOA of this "reply" is determined by the timing of the "F1" pulse. Since the code bits of such an artificially created reply are not valid, the logic tags this as an F2-tracking reply. (The tag appears in the reply listing (Figure 5-1) as a one in the first digit of the 6-digit group showing the transponder code). If in fact an actual reply is partially obscured by self-garble, but a number of the code pulses, as well as the F2 bracket pulse, are received in the clear, an artificial F1 pulse will be created for every such pulse received. The result will be that a whole burst of partially overlapping replies will be decoded, all tagged as artifical. If the self-garble condition persists for a number of radar interrogations, there may be enough of these artificial replies to result in target declarations. Targets so declared will have the identity and altitude codes indicated as garbled.

A group of replies including replies obtained by F2 tracking will be formed into a target report with a valid identity code only if there are at least four mode A (identity) replies received in the clear. Target reports containing replies generated by F2 tracking are associated with target tracks (record correlation) only if this condition is met.

This, in general, will happen if part of the burst of replies from another aircraft are subject to self-garble and part are received in the clear. The artificially restored self-garbled replies included in the target report insure that the full burst of replies from the target aircraft is considered in determining the target centroid - i.e. in establishing the correct differential azimuth. The extraneous replies and targets that may be created by falsely assuming some code pulses to be F2 pulses are rejected

```
LCAS QUICK LOOK PROGRAM                                                              DATE 23 NOV 1976    PAGE    0366
TOA/DAZ REPLY LISTING FOR RADAR G SCAN    72

INTERROGATION TIME: 307014729.197     MODE: C     DAZ:   .45L
  -.870  102010   -.290  106130  77.720  005774
INTERROGATION TIME: 307017354.568     MODE: A     DAZ:   .21L
 50.025  000200
INTERROGATION TIME: 307019980.084     MODE: A     DAZ:   .03R
  -.435  100311
INTERROGATION TIME: 307022605.453     MODE: C     DAZ:   .27R
  -.870  102010
INTERROGATION TIME: 307027856.338     MODE: A     DAZ:   .75R
  -.870  100211   -.290  100211
INTERROGATION TIME: 307030481.709     MODE: C     DAZ:   .99R
 14.790  100000
INTERROGATION TIME: 307033107.078     MODE: A     DAZ:  1.23R
 10.440  120000  11.890  100004  13.340  100404  14.790  100406
INTERROGATION TIME: 307035732.594     MODE: A     DAZ:  1.47R
  -.580  100311   1.740  104200  10.440  122100  11.890  110024  13.340  105404  14.790  100456
INTERROGATION TIME: 307038357.963     MODE: 0     DAZ:  1.71R
 14.790  100000
INTERROGATION TIME: 307040983.478     MODE: A.    DAZ:  1.95R
  -.580  100211   1.740  124200   6.090  130022  10.295  122102  11.745  110224  13.195  105405
 14.645  100556
INTERROGATION TIME: 307043608.848     MODE: A     DAZ:  2.19R
  -.580  100311   1.740  120200   6.090  130002  10.440  122102  11.890  110224  13.340  105405
 14.645  100556
INTERROGATION TIME: 307046234.363     MODE: C     DAZ:  2.43R
 14.645  100000
INTERROGATION TIME: 307048859.588     MODE: A     DAZ:  2.67R
 -8.990  014000   6.235  130000  10.440  122002  11.890  100224  13.340  101405  14.790  100516
 75.980  007200
INTERROGATION TIME: 307051485.103     MODE: A     DAZ:  2.91R
 10.440  120000  11.745  100004  13.195  100404  14.645  100406
INTERROGATION TIME: 307054110.473     MODE: C     DAZ:  3.15R
  -.435  100000
INTERROGATION TIME: 307056735.988     MODE: A     DAZ:  3.39R
  -.435  100211  10.295  120000  11.745  100004  13.195  100404  14.645  100406
INTERROGATION TIME: 307059361.213     MODE: A     DAZ:  3.63R
 -3.915  012304   1.885  026621   6.235  034033   7.540  025344  10.440  026526  14.790  000777
INTERROGATION TIME: 307061986.728     MODE: C     DAZ:  3.87R
 14.790  004220
INTERROGATION TIME: 307064611.953     MODE: A     DAZ:  4.12R
  7.685  024374   9.135  033445  12.035  011666  14.935  000777
INTERROGATION TIME: 307067237.469     MODE: A     DAZ:  4.36R
  7.540  024374   8.990  033445  11.890  011666  14.790  000777
INTERROGATION TIME: 307069862.838     MODE: C     DAZ:  4.60R
 14.935  004220
INTERROGATION TIME: 307072488.353     MODE: A     DAZ:  4.84R
  7.540  024374   8.990  033445  11.890  011666  14.790  000777
INTERROGATION TIME: 307075113.723     MODE: A     DAZ:  5.08R
```

FIGURE 5-1. TOA/DAZ REPLY LISTING

by later screening steps in the BCAS logic, so that no false alarms will be created.

5.10.2 Example of F2 Tracking

The operation of the F2 tracking algorithm was verified by examining reply level BCAS data collected on November 9, 1976. The flight test consisted of flying radial patterns near the Mispah fire tower. The transponder in the fire tower was replying with the identity code 0777. For this code, the train of pulses is shown in Figure 5-2.

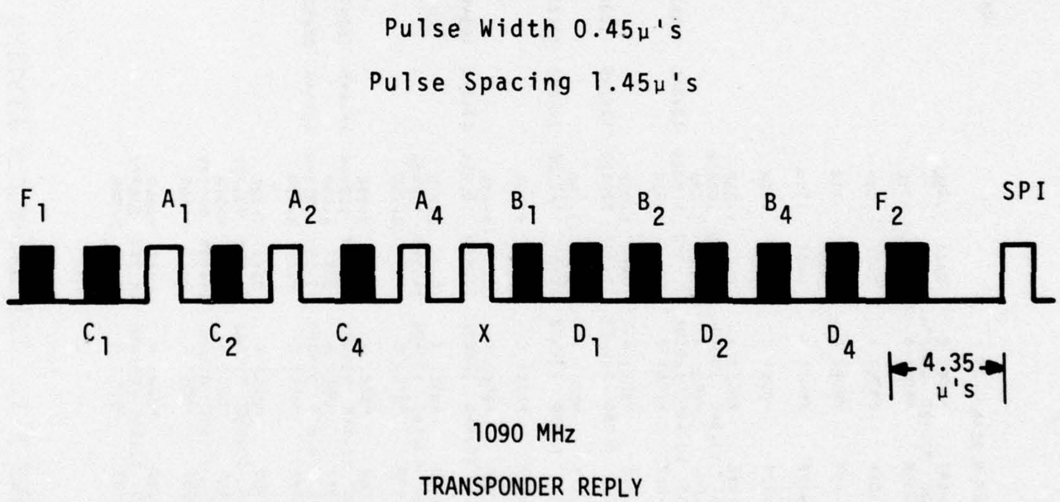


FIGURE 5-2. CODE 0777 MODE 3/A REPLY

A timing diagram of self-garbled interference and F2 tracking is shown in Figure 5-3. The sampling of the replies received and the resulting TOA histograms and target reports generated is shown in Figures 5-4 to 5-6. A detailed bit-by-bit reconstruction of the replies registered to the mode 3/A interrogation at a differential azimuth of 1.95° right is shown in Figure 5-5.

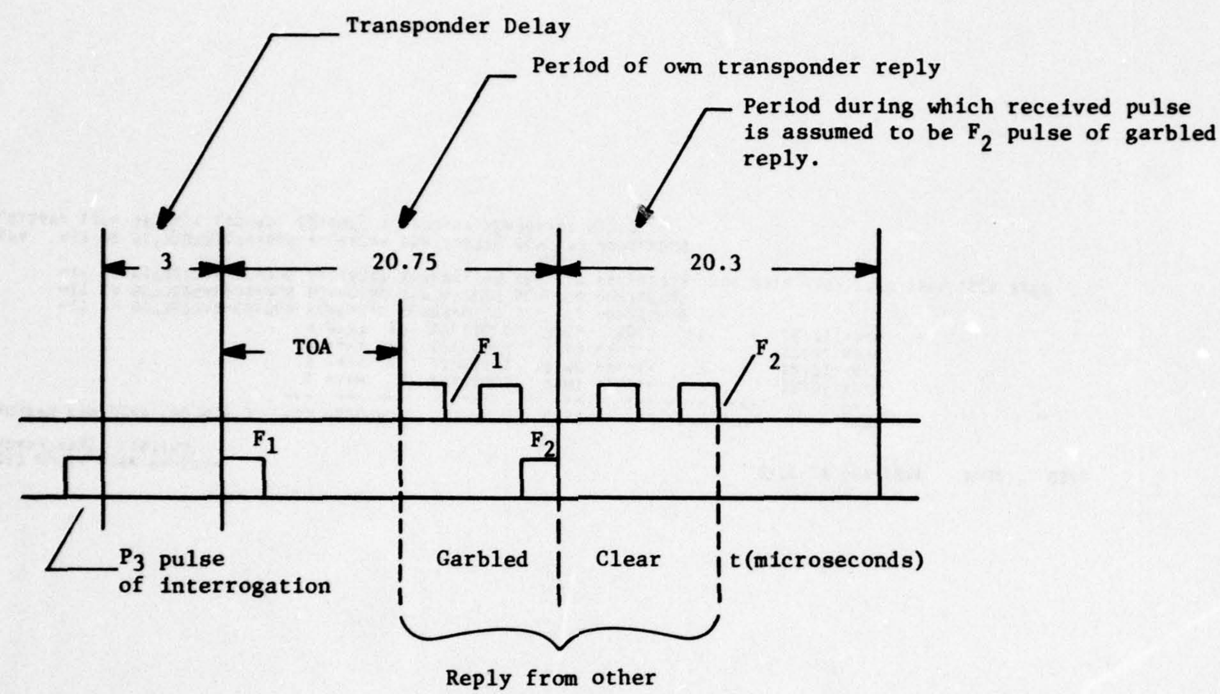


FIGURE 5-3. TIMING DIAGRAM OF SELF-GARBLE INTERFERENCE AND F2 TRACKING

```
LCAS QUICK LOOK PROGRAM                                                DATE 23 NOV 1976    PAGE    0371
RADAR/TARGET LISTING

TARGETS FOR SCAN  72 RID G    TID  BCD NRP     TOA       DAZ    TAL LTRN GTRN          TIME
                              ---  --- ---     ---       ---    --- ---- ----          ----
                                1 ****   8  10.830US   1.97 ******                  12:31:48.5
                                2 ****  10  12.280US   2.52 ******                  12:31:48.5
                                3 ****   7  13.710US   1.83 ******                  12:31:48.5
                                4 C777  15  15.180US   2.55   5CCC   20      2      12:31:48.5
     WIT 14 BCT3C7847402.0US ACACACAC SCP23.550S SCN   C PRP2536US
     WIT 18 BCT308646233.8US ACAACAAC SCP 4.702S SCN   C PRP3222US
     WIT 26 BCT31C116150.3US AACAACAA SCP23.474S SCN   C PRP1823US 1904 2318 2867 2257 1864 1924 3159

ASR4   WIT 22 BCT31C957074.6US AACAACAA SCP 3.937S SCN  73 PRP2625US
SLS1268/ 120. 599 NIN 145 BAL 10400FT AWN272.57 ACH286.61 RID G
```

FIGURE 5-4. TARGET REPORTS

Identity Altitude Codes	LCAS QUICK LOOK PROGRAM TOA DIFFERENTIAL AZIMUTHS		DATE 23 NOV 1976 PAGE 0368 FOR RADAR G SCAN 72
	.000	5.08R 5.56R 5.80R 7.00R 7.72R	
	.145	7.24R	
	•••••••		
C_4	1.740	1.47R 1.95R 2.19R	
	1.885	3.63R	
	•••••••		
B_1	6.090	1.95R 2.19R	
	6.235	2.67R 3.63R	
	•••••••		
D_1	7.540	3.63R 4.36R 4.84R	
	7.685	4.12R	
	•••••••		
B_2	8.990	4.36R 4.84R10.60R	
	9.135	4.12R	
	•••••••		
D_2	10.150	6.32R	
	10.295	1.95R 3.39R	
	10.440	1.23R 1.47R 2.19R 2.67R 2.91R 3.63R	
	•••••••		
B_4	11.745	1.95R 2.91R 3.39R	
	11.890	1.23R 1.47R 2.19R 2.67R 4.36R 4.84R	
	12.035	4.12R	
	12.180		
	12.325		
	12.470		
	12.615		
	12.760	.69L	
	12.905		
	13.050		
D_4	13.195	1.95R 2.91R 3.39R	
	13.340	1.23R 1.47R 2.19R 2.67R	
	13.485		
	13.630		
	13.775		
	13.920		
	14.065		
	14.210	.69L	
	14.355		
	14.500	15.35L	
F_2	14.645	1.95R 2.19R 2.43R 2.91R 3.39R	
	14.790	.99R 1.23R 1.47R 1.71R 2.67R 3.63R 3.87R 4.36R 4.84R	
	14.935	4.12R 4.60R	
	15.080	13.43L	
	15.225		
	15.370		
	15.515	.69L	
	15.660		
	15.805		

FIGURE 5-5. HISTOGRAM TABLE

Reply of Transponder		Pulses Received	Replies decoded using F2 tracking (C indicates artificial pulse)					
	Obscured by own reply		F1 C					
			C1					
			A1					
			C2	F1 C				
			A2	C1				
			C4	A1				
			A4	C2	F1 C			
			X	A2	C1	F1 C		
			B1	C4	A1	C1	F1 C	
F1 X			D1	A4	C2	A1	C1	F1 C
C1 X		X	B2 X	X X	A2 X	C2 X	A1 X	C1 X
A1 0			D2	B1	C4	A2	C2	A1
C2 X			B4	D1	A4	C4	A2	C2
A2 0			D4	B2	X	A4	C4	A2
C4 X	Received in clear	X	F2 X	D2 X	B1 X	X X	A4 X	C4 X
A4 0				B4	D1	B1	X	A4
X 0				D4	B2	D1	B1	X
B1 X		X	SPI X	F2 X	D2 X	B2 X	D1 X	B1 X
D1 X					B4	D2	B2	D1
B2 X					D4	B4	D2	B2
D2 X		X		SPI X	F2 X	D4 X	B4 X	D2 X
B4 X		X				F2 X	D4 X	B4 X
D4 X		X					F2 X	D4 X
F2 X		X			SPI X			F2 X
						SPI		
							SPI	
SPI 0								SPI
Code decoded:			120200	130002	122102	110224	105405	100556

FIGURE 5-6. REPLIES DECODED BY F2 TRACKING AT DAZ = 2.19°R (cf. FIG. 5-1). C IS ARTIFICIAL PULSE

The TOA of the replies from the test transponder is 14.79 microseconds. Thus only the last 14.79 microseconds of the reply - i.e., the last 10 pulse positions are received in the clear. (See Figure 5-6.) For every bit received in the 20.3 microsecond interval following the OWN reply, an artificial F1 pulse is generated. The code bits corresponding to every such bracket are decoded (see Figure 5-1). The resulting replies are included in the TOA histogram (Figure 5-5) and target reports are generated according to the usual rules (Figure 5-3). Only the proper target report is found not garbled and associated with a global track. Thus proper operation is demonstrated.

5.11 FRUIT MEASUREMENTS

The Fruit Susceptability program was exercised to process BCAS type 3 messages (i.e., beacon reply data) for runs 1 through 12 of JTIDS testing. Six of these runs, that is when the JTIDS system was OFF, are germane to this report. The results of the data reduction program for these runs are tabulated in Table 5-9.

For the purpose of this discussion, fruit replies are defined as those transponder replies received by BCAS which the software was unable to correlate to target reports.

This reply/target report correlation was performed via the mechanism of histogram tables (see Figure 5-3), requiring the receipt of a minimum of six replies to fall into no more than three contiguous TOA bins, with each TOA bin having a granualrity of 0.145μ seconds.

As shown in Table 5-9, the data depicted are for one radar, the ASR-5, and are averages on a per scan basis. The fruit rate varies between 51.4% and 64.7%. The total number of replies, again on a per scan basis, varied between 121.9 and 143.6.

Figure 5-3 depicts the replies received by BCAS for one scan in a histogram table format. As seen in the figure, each fruit reply generally constitutes a single entry in one of the many TOA bins.

TABLE 5-9. FRUIT AND TRANSPONDER REPLIES PER SCAN

Fruit Replies

Run #	N	m	s^2	m	s^2	% of Fruit
1	98	73.765	454.244	143.612	999,186	51.36%
2	127	78.315	1015.761	129.291	1447.194	60.57%
5	100	86.050	525.372	145.880	944.825	58.99%
6	105	78.190	287.031	131.114	733.760	59.64%
9	93	69.656	542.191	127.731	784.952	54.53%
10	87	78.920	642.420	121.897	808.834	64.74%

5.12 NORTH PULSE DETECTION

During JTIDS testing, North pulse measurements were obtained for radial runs in the vicinity of Mizpah. The North/South pulses were transmitted for 32 consecutive scans beginning at North crossing and another 16 pulses were transmitted every other scan beginning at South crossing for a total of 48 pulses per scan.

The average number of North pulses (see Table 5-10) received per antenna rotation is approximately 47 within a deviation of approximately 5. The standard deviation appears to vary with time due to causes we cannot explain; i.e., it is significantly different for different runs.

It follows from the observed mean and standard deviation that some North pulses are not being detected and in other instances noise is being accepted as North pulses.

5.13 JTIDS INTERFERENCE MEASUREMENTS WITH BCAS

5.13.1 Introduction

Special flight tests were conducted to obtain data on the compatibility of JTIDS (Joint Tactical Information Distribution System) with the semi-active model of the Beacon Collision Avoidance System (BCAS). This mode of BCAS requires the transmission of antenna-position pulses (north and south) from ATCRBS ground interrogators. Since no simulator exists for this purpose, the flight tests were, of necessity, conducted in the FAA-established BCAS developmental test area around Atlantic City, N.J., where a number of interrogators have been modified to produce azimuth reference pulses. This area does not represent a worst-case BCAS environment. During the BCAS flight tests, the JTIDS transmitter was operated in the wideband double-pulse 40%/40% mode with notch filters installed at 1030 MHz and 1090 MHz. JTIDS peak power was 165 watts. The test plan and resulting measurements are contained in Reference 3.

TABLE 5-10. NORTH PULSES DETECTED PER ANTENNA ROTATION

JTIDS Off				JTIDS On			
Run #	N	m	s^2	Run #	N	m	s^2
1	101	45.059	9.076	3	129	47.698	15.962
2	129	48.550	10.647	4	153	47.576	14.437
5	101	46.336	11.346	7	107	46.252	25.261
6	110	46.127	45.305	8	89	46.933	56.626
9	96	48.771	10.642	11	81	46.148	5.292
10	117	48.103	32.868	12	99	46.253	8.950
TOTAL	654	47.033	21.539		663	46.927	28.856

This section provides a description of BCAS, particularly of the measurements made by the system to track threat aircraft. In addition, the statistical tests are described that were used to assess the effect of JTIDS on BCAS signal-detection capability and measurement accuracy.

5.13.2 Equipment Tested

When the JTIDS EMC (Electro Magnetic Compatibility) tests were being conducted, the BCAS program was in the developmental stage with the active and passive mode hardware undergoing flight tests. The active and passive hardware were built using, to the maximum extent possible, off-the-shelf equipment. They were built to demonstrate the BCAS concept and were not representative of an optimized design. The susceptibility of the BCAS passive mode to a JTIDS signal environment was tested. The ATCRBS transponder portion of the BCAS system was effectively tested under the ATCRBS tests.

5.13.3 Applicability of Measurements to the Active Mode of BCAS

Identical 1090 MHz receiver front ends are employed in BCAS for both the active and passive mode because the basic signal structures associated with transponder replies to either BCAS interrogations (active mode) or ATCRBS ground beacon interrogations (passive mode) are identical. Therefore, the results of the BCAS passive tests can, to some degree, be extrapolated to the active mode of BCAS.

5.13.4 Flight Tests

Test flights were flown at NAFEC on January 6 and January 7, 1977, to evaluate the effects of JTIDS signals on the BCAS system. The BCAS-equipped aircraft was an FAA-owned Grumman Gulfstream (G-159) test-bed aircraft from NAFEC. The JTIDS-equipped aircraft was an Air Force Flight Inspection C-140 Jetstar. The aircraft were flown in tandem at a vertical separation of 1000 feet with a top-mounted antenna on the lower aircraft and a bottom-mounted

antenna on the upper aircraft to maximize coupling as described in Reference 3.

Accuracy of Measurements. The primary question of interest here is whether the accuracy in the measurement of TOA and DAZ is affected by the presence of JTIDS signals. Two series of flights were flown. In the first set of runs, the BCAS aircraft, tracked by the C-band Extended Area Instrumentation Radar (EAIR) at NAFEC, flew past a fixed ATCRBS transponder (Mizpah Tower). The BCAS system recorded six types of data, including the differential azimuth between the BCAS aircraft and the fixed transponder as seen from the Air Traffic Control Beam Interrogator (ATCBI-3), which is collocated with the NAFEC ASR-5, and the TOA of the replies to the ATCBI-3 from the fixed transponder. On alternate sets of outbound and inbound runs, the JTIDS was turned on. The measured values of TOA and differential azimuth were compared with predicted values computed from the geometry, as determined from the surveyed positions of the radar and transponder and the position of the aircraft as measured by the EAIR radar. On the same runs, statistics were gathered on the number of azimuth reference pulses per antenna rotation that were detected by the BCAS system and the number of fruit replies received.

Quality of Radar Lock. The primary question in this case is whether JTIDS signals affect the ability of BCAS to detect radar mainbeam and SLS signals. Longer runs radially away from and toward the radar were flown throughout this portion of the test. Counts of the mainbeam and SLS pulses were taken for each scan of the ATCBI-3 while the JTIDS was turned on or off every thirty seconds. The radial runs were flown in from or out to the acquisition/loss-of-lock range.

5.13.5 Analysis

TOA Measurements. Measurements of the TOA of the signal from the fixed transponder in the Mizpah Fire Tower were made during 12 radial runs past the tower, six inbound and six outbound. The

JTIDS transmitter was on for half the runs and off for the other half. The BCAS-equipped aircraft was tracked by the C-band EAIR radar. The expected TOA at the time of each ATCBI-3 mainbeam passage was computed, using the kn own positions of the ATCBI-3 and the fixed transponder and the position of the BCAS aircraft as measured by the EAIR radar. The differences between the predicted (computed) TOA and the measured TOA were calculated and their sample means, m, and sample variances, s^2, were tabulated. No EAIR measurements were taken during Run 12 (see Table 5-11).

TABLE 5-11. TOA DIFFERENCES IN MICROSECONDS BETWEEN BCAS MEASUREMENTS AND VALUES PREDICTED ON THE BASIS OF EAIR MEASUREMENTS WITH A JTIDS DOUBLE PULSE WAVEFORM AT A 40%/40% TIME SLOT DUTY FACTOR

JTIDS Off				JTIDS On			
Run #	N	m	s^2	Run #	N	m	s^2
Outbound							
1	53	.238	.042	3	57	.205	.024
5	58	.220	.024	7	51	.242	.027
9	59	.240	.027	11	53	.242	.028
(1,5,9)	170	.233	.030	(3,7,11)	161	.230	.026
Inbound							
2	58	.169	.018	4	60	.171	.013
6	55	.197	.012	8	56	.187	.015
10	63	.209	.017	12	(no EAIR data)		
(2,6,10)	176	.192	.016	(4,8)	116	.179	.014

N = number of samples in set
m = sample mean of data in set
s^2 = sample variance of data in set

The measurements show that, independent of JTIDS, there was a difference between measurements on the inbound and outbound runs. Since each point in space at which a measurement was made was unique and had no precise counterpart on any other run, there is no reason to treat the runs as closed entities to be considered separately. In view of this, it is appropriate to test separately the inbound data and the outbound data. Thus, all measurements made under the same set of circumstances (e.g., outbound with JTIDS off, Runs 1, 5 and 9) were aggregated. The question of interest is whether JTIDS adversely affects TOA measurements, i.e., tends to increase the variance. Thus a one-tailed F-ratio test is appropriate (Natrella, Section 4-2.2).

If N_A and N_B are the number of measurements in each of the two sets, $1-\alpha$ is the confidence level of the result, and ${s_A}^2$ and ${s_B}^2$ are sample variances of these two measurement sets, then the ratio of the sample variances, F, is computed by

$$F = {s_A}^2/{s_B}^2 \qquad 5.13\text{-}1$$

If $F > F_{1-\alpha}$ for N_A-1 and N_B-1 degrees of freedom, then the variability of the measurements with JTIDS on exceeds the variability of measurements when JTIDS is not present. Otherwise, there is insufficient evidence to assert that JTIDS affects the measurements. The level of significance of the test was set at .05, i.e., the probability of falsely concluding that a difference exists. $F_{1-\alpha}$ is the $1-\alpha$ percentile of the F distribution with N_A-1 and N_B-1 degrees of freedom, i.e., the 95% confidence level.

It is to be noted from Table 5-11 that, in fact, the variance is less with JTIDS on than with JTIDS off in both instances. (The same is true of the mean differences between measured and predicted TOA measurements, i.e., the systematic bias error.) The computed F values for the outbound and inbound data are 0.867 and 0.875, respectively. The critical F value for a 95% confidence level was found to be approximately 1.23.

Therefore, clearly, the results lead to the conclusion that JTIDS does not increase the variability.

Differential Azimuth Measurements. The differential azimuth measurements were made at the same time as the TOA measurements, and the differences between measured and predicted differential azimuths were calculated in the same way as TOA differences. They are shown in Table 5-12. The difference between the predicted azimuth and measured azimuth, as a function of antenna scan were computed.

Again, there is a tendency for the sample variances to be greater on the outbound legs than on the inbound, though the difference is not as great as in the case of the TOA measurements. It was nevertheless decided to analyze the two cases separately. Again α, the significance level of the tests, was set at 5%, and a test was made to determine whether there is reason to believe that, with JTIDS on, the random errors in measuring differential azimuth are greater than with JTIDS off. The computed F values for the outbound and inbound measurements were 0.874 and 0.921, respectively. Again, the critical F value for a 95% confidence level was found to be approximately 1.23. Clearly, since the sample variance with JTIDS on is actually smaller, the results of the test are that one must conclude that the random errors in measuring differential azimuth are not affected by JTIDS pulses.

Fruit. The number of fruit replies detected by the BCAS (transponder replies received that the BCAS system could not correlate with any target) was recorded for Runs 1 through 12, i.e., the flights past the fixed transponder. The fruit reply data are tabulated in Table 5-13. The data for Runs 2 and 4 are anomalous. When compared to the rest of the data, the variances are excessively large. In addition, the mean number of fruit replies per scan on Run 4 was 132, which is more than 40% higher than the run with the next higher mean fruit rate, i.e., Run 11. To avoid having any such extraneous values influence the results,

TABLE 5-12. DIFFERENTIAL AZIMUTH IN DEGREES BETWEEN BCAS MEASUREMENTS AND VALUES PREDICTED ON THE BASIS OF EAIR MEASUREMENTS WITH A JTIDS DOUBLE PULSE WAVEFORM AT A 40%/40% TIME SLOT DUTY FACTOR

JTIDS Off				JTIDS On			
Run #	N	m	s^2	Run #	N	m	s^2
Outbound							
1	53	-.061	.157	3	56	-.076	.152
5	58	-.125	.077	7	51	-.149	.099
9	59	-.065	.129	11	53	-.139	.060
(1,5,9)	170	-.084	.119	(3,7,11)	161	-.119	.104
Inbound							
2	58	-.107	.111	4	60	-.106	.111
6	55	-.101	.079	8	56	-.114	.075
10	63	-.158	.114	12	(no EAIR data)		
(2,6,10)	176	-.127	.102	(4,8)	116	-.110	.094

N = number of samples in set

m = sample mean

s^2 = sample variance

TABLE 5-13. NUMBERS OF FRUIT REPLIES DETECTED PER SCAN WITH JTIDS DOUBLE PULSE WAVEFORM AT A 40%/40% TIME SLOT DUTY CYCLE

JTIDS Off				JTIDS On			
Run #	N	m	s	Run #	N	m	s
1	53	73.765	454.244	3	125	86.768	621.056
2	127	78.315	1015.761	4	138	132.486	1079.451
5	100	86.050	525.372	7	95	72.211	435.390
6	105	78.190	287.031	8	87	75.605	332.296
9	93	65.656	542.191	11	81	92.222	454.372
10	87	78.920	646.990	12	90	87.622	470.847
Total*	438	76.933	481.750		478	82.929	470.231

*Total values do not include anomalous data from Runs 2 and 4.

the data from Runs 2 and 4 were excluded when the aggregated data for runs with JTIDS off were compared with the aggregated data for runs with JTIDS on.

The test performed to determine if the mean number of fruit replies differed depending upon whether JTIDS was on or off is a generalization of the two-sized t-test (Natrella, Section 3-3.1.2). Since the variances of two populations being compared cannot be assumed to be equal, a test procedure must be applied in which the stated significant level is only approximately achieved. The approximation is good provided N_A and N_B are not too small. First, an effective number of degrees of freedom must be computed for the test. This value is given by f', the nearest integer to

$$f = \left[\frac{(V_A + V_B)^2}{\dfrac{V_A{}^2}{N_A+1} + \dfrac{V_B{}^2}{N_B+1}} \right] - 2 \qquad 5.13\text{-}2$$

where

$$V_A = \frac{S^2{}_A}{N_A}, \quad V_B = \frac{S^2{}_B}{N_B}$$

and $S^2{}_A$ and $S^2{}_B$ are the pooled variances of the two populations and N_A and N_B are the number of samples in each. The statistical test consists of computing from the table value of $t_{1-\alpha/2}$, for f' degrees of freedom, the quantity

$$\delta = t_{1-\alpha/2} \sqrt{V_A + V_B} \qquad 5.13\text{-}3$$

If $|m_A - m_B|$ is greater than δ where m_A and m_B are the grand means for JTIDS on and JTIDS off, respectively, one concludes that the data differs with regard to average performance. The test was performed at a level of significance of 5%. The effective degree of freedom, f', was found to be 914 and the corresponding table value for $t_{.975}$ was approximately 1.96. Thus, δ was found to be

2.829 and $|m_A - m_B|$ was found to be 5.995. Since 5.995 is larger than δ, one must conclude that, with 95% confidence, there is sufficient evidence to indicate significant difference in the two mean fruit reply rates.

Thus it appears that the JTIDS signals did have some effect on the number of fruit replies received by BCAS. However, since the meaningful performance parameters of the system -- the TOA and differential azimuth measurements -- do not appear to be affected by JTIDS, the change in fruit rate is of no practical significance. For instance, the TOA measurements of the run with the highest fruit rate were considerably better than the average for all runs.

Azimuth Reference Pulse Detection. The BCAS system continuously acquired the azimuth references pulses transmitted by the ATCBI-3. The number of such pulses detected per antenna rotation period was typed out on the system teletype for each rotation period.

These data for Runs 1-12 past the Mizpah Tower are shown in Table 5-14. No definite conclusion can be drawn from these data, since there is too much BCAS system variability among runs. For example, with JTIDS-off and the aircraft flying the inbound leg, the variance is 10.65 on Run 2 and 45.31 on Run 6.

The radar emitted 48 pulses per rotation, 32 consecutively after passing north and 16 on alternate interrogations after passing south. Both misses and false detections may occur. Misses and false detections during the same scan would offset each other with respect to the number of detected pulses. Thus, the net number of pulses received is, in itself, not a very good indication of system performance, but no other measurable parameter was available in the BCAS model tested.

The overall net difference between the mean number of azimuth reference pulses detected with JTIDS on and JTIDS off is slight ($\approx$ .90 per scan). The variance varies greatly from run to run, both with JTIDS on and JTIDS off. No consistent pattern to this variation is evident, as a function of either time or flight

TABLE 5-14. AZIMUTH REFERENCE PULSES DETECTED PER ANTENNA SCAN WITH A JTIDS DOUBLE PULSE WAVEFORM AT A 40%/40% TIME SLOT DUTY FACTOR

JTIDS Off				JTIDS On			
Run #	N	m	s^2	Run #	N	m	s^2
1	101	49.059	9.076	3	129	47.698	15.962
2	129	48.550	10.647	4	158	47.576	14.437
5	101	46.336	11.346	7	107	46.252	25.261
6	110	46.127	45.305	8	89	46.933	56.626
9	96	48.771	10.642	11	81	46.148	5.292
10	117	48.103	32.868	12	99	46.253	8.950
Total	654	47.832			663	46.927	

N = number of scans
m = sample mean
s^2= sample variance

direction. Thus, there is no satisfactory test for determining the true influence of JTIDS on the number of azimuth reference pulses received. The effect, if any, is small relative to the inherent variability in the number of pulses detected scan to scan.

Mainbeam Hits. The second series of tests consisted of tandem flights of approximately 200 nautical miles (see Reference 1), with the JTIDS transmitter turned on and off for alternating 30-second intervals. One radar antenna scan immediately preceding and one immediately following the instant that the JTIDS receiver was switched on or off were disregarded in analyzing the data on mainbeam hits. This was done to assure that mainbeam passage was not associated with the wrong condition of JTIDS.

Examination of the plots (see Reference 1) of mainbeam hits detected as a function of time shows that both the number of mainbeam pulses and the P_2 SLS pulse ratio tend to increase as the aircraft approaches the radar, and tend to decrease as the aircraft flies away from the radar. This decrease continues until radar lock is lost. No qualitative difference can be detected in the plots associated with the intervals when JTIDS was on or off.

The data for Runs 16 and 18 are anomalous. The data shows that, on Run 16, JTIDS-off data displays the maximum variability measured for the baseline, while on the same run the JTIDS-on data displayed the minimum variability measured for the test data. Run 18 was similar; however, this time the maximum variability was measured for JTIDS-on data while the minimum variablitiy was displayed by the JTIDS-off baseline data. These two runs were excluded from the statistical tests. However, there is evidently a great deal more similarity in the number of mainbeam hits sensed during each run with JTIDS on or JTIDS off than there is between runs (see Table 5-15). Accordingly, statistical tests were performed on the results of each run separately. Two tests were performed, the F-ratio test for equal variances and the generalized two-sided t-test for equal means. The variability of the number of mainbeam hits per mainbeam passage with JTIDS off and with JTIDS on was compared. The first F-test at the level of significance

α = .05 was used. The difference in the mean number of hits and the effective degrees of freedom, f', were computed for each run; then the generalized two-sided t-test at the level of significance α = .05 was performed (Natrella, Section 3-3.1.2).

The data and the formal results of these tests are shown in Table 5-15. At 95% confidence, a difference in the variability of mainbeam hits with JTIDS off and with JTIDS on was found only in Run 22. No significant differences in the mean number of mainbeam hits were found at the α = .05 significance level. Thus the measures used indicate that JTIDS does not affect the ability of BCAS to detect ATCRBS mainbeam interrogations.

Side Lobe Suppression (SLS) Ratio. The ratio of the number of side lobe suppression pulses detected by the BCAS system to the total number transmitted per ATCRBI-3 antenna rotation was monitored on the same flights in which the number of detected mainbeam pulses were monitored. The same statistical tests were performed on the means and variances to decide whether the JTIDS system influenced the results. The F-test at the α = .05 level of significance was used to test whether the variances of the measurements differed significantly, and the generalized two-sided t-test at the α = .05 level of significance was used to compare the average number of SLS pulses received per antenna rotation. The effective degrees of freedom, f', was calculated for each run and the corresponding table value for $t_{.975}$ was selected for the t-test computation. The data is plotted in Reference 3 and the results are presented in Table 5-16. The variance is significantly different on one run. Therefore, the difference in the average number of SLS pulses detected is declared to be statistically significant only on this run since the other nine runs passed the tests. Hence, the tests do not show any tendency of JTIDS to affect the number of SLS pulses detected by the BCAS system.

Again, the plots of the data are more meaningful and informative. They show variation in the SLS ratio with respect to range from radar, but no perceptible difference that can be associated with whether JTIDS was on or off.

TABLE 5-15. NUMBER OF MAIN BEAM HITS PER SCAN

	JTIDS Off			JTIDS On			Statistical Results		
Run #	N	m	s^2	N	m	s^2	F-ratio	f'	t-test
14	18	7.833	19.909	22	7.455	23.785	S	40	S
15	52	14.000	18.080	54	13.352	22.724	S	105	S
16	18	13.389	25.543	17	15.059	1.309	AD	19	AD
17	26	11.462	17.775	31	12.871	11.985	S	50	S
18	9	13.444	3.779	4	6.000	48.609	AD	3	AD
19	40	12.425	23.688	34	13.118	23.503	S	72	S
20	39	12.615	21.818	40	13.700	16.777	S	77	S
21	23	11.261	17.024	21	9.095	29.987	S	39	S
22	83	17.000	14.684	83	17.506	8.620	D	155	S

N = number of scans in sample level
m = sample mean
s^2= sample variance
AD= Anomalous Data
S = Same Population
D = Different Population

TABLE 5-16. SLS RATIO FOR EACH SCAN WITH A JTIDS DOUBLE PULSE WAVEFORM AT A 40%/40% TIME SLOT DUTY FACTOR

	JTIDS Off			JTIDS On			Statistical Results		
Run #	N	m	s^2	N	m	s^2	F-ratio	f'	t-test
13	25	58.084	635.242	30	62.011	565.679	S	52	S
14	18	81.380	5.449	22	82.077	17.775	D	35	S
15	52	63.217	635.695	54	62.066	571.121	S	105	S
16	18	65.547	554.085	17	75.163	107.081	S	24	S
17	26	29.142	698.809	31	40.047	653.723	S	55	S
18	9	58.863	154.928	4	26.064	388.326	S	5	D
19	40	53.409	608.116	34	53.529	724.740	S	70	S
20	39	52.375	857.143	40	50.015	787.925	S	79	S
21	23	45.035	908.661	21	47.856	454.144	S	41	S
22	83	78.641	169.911	22	81.579	83.759	S	149	S

N = number of scans in sample

m = mean sample

s^2 = sample variance

S: Same Population

D: Different Population

5.13.6 Summary of Results

These tests attempted to determine the compatibility of JTIDS with a future BCAS system. Since BCAS is still under development, testing was limited to the Litchford semi-active system model. The JTIDS transmitter was operated in the wideband double-pulse mode with a 40%/40% time-slot duty factor and with notch filters installed at 1030 MHz and 1090 MHz. The JTIDS system peak power was 165 watts.

The active system was not tested since the same equipment was included in the ATCRBS tests and, therefore, the ATCRBS results can be used as an indication of compatibility.

The results of the statistical analysis of the flight data from the semi-active system indicate the following:

1. The presence of JTIDS does not affect the ability of the BCAS to measure differential time of arrival (TOA) or differential azimuth (DAZ).

2. The number of fruit replies was increased by 6 replies per radar scan (77 to 83) when the JTIDS signal was present; however, this did not appear to influence the BCAS performance.

3. JTIDS had no significant affect on the mean number of mainbeam hits or the side lobe suppression ratio.

For a more complete analysis, the reader should examine the data plots in Reference 1. A visual comparison of the BCAS measurements with JTIDS off and JTIDS on clearly shows that JTIDS does not influence the BCAS system. For example, regardless of the JTIDS condition, examination of the mainbeam data shows only that the number of mainbeam pulses tends to increase as the aircraft approaches the radar and to decrease as the aircraft flies away from the radar. However, while there were no major areas of interference, care should be taken in the development of the two systems to insure continued compatibility.

5.14 FALSE ALARMS/FALSE TRACKS AND MISSED ALARMS/MISSED TRACKS

Assessments for false alarms/false tracks and missed alarms/missed tracks were made by comparing BCAS data with ARTS III data. The ARTS III data extraction tapes were processed by both the Flight History program and the Widened Azimuth Window program. The BCAS tapes in turn were processed by the BCAS Detailed Processing Programs. A brief discussion of these programs follows.

A flight history listing outputs (Figure 5-7) information consisting of scan number, time, aircraft identification, beacon code, altitude, range, azimuth, run length and number of transponder replies. These entries are in numberical ascending sequence of scan numbers for the specific aircraft, with the aircraft ordered in sequence by beacon code. The widened azimuth window program processes ARTS III target report messages of aircraft that are present in the widened azimuth window of BCAS. In this instance, it processes ASR-4 radar target messages that are within a $\pm 18°$ window of OWN. Figure 5-8 depicts a widened azimuth window output listing. The output is on a per scan basis and contains beacon code, time, range, azimuth, altitude, TOA, DAZ, range, bearing, run length and number of transponder replies. The BCAS detailed processing program listing, Figure 5-9, contains target report information grouped on a per radar basis with global track data interspersed. A list of abbreviations include:

SCAN:	scan number
RID B:	interval radar identification
TID:	target identification
BCD:	beacon code
NRP:	number of transponder replies
TOA:	time of arrival in μ seconds
DAZ:	differential azimuth
TAL:	target's altitude
OAL:	OWN's altitude
LTRN:	local track number.

SUB-SYSTEM 1 ASSIGNED BEACON CODE 4366 TAPE ID: 0067 FILE 1 SEGMENT 1 PAGE 53

SCAN	TIME	ACID	RBC	C	ALT	RANGE	AZIMUTH	VELOCITY	DIRECTION	FIRM	W/S	VA	VC	RUN	HIT
14	12:50:18				106	25.00	136.76	ACAACAACAACAA			1	3	3	13	13
15	12:50:23	N47	4366	1	106	24.81	207,07	144.27	316,97	37					
15	12:50:23				105	24.81	207,25	AAC.ACAACAACAAC.ACA			1	3	3	19	17
15	12:50:22				105	24.94	136.76	AACAA.AACAACAAC			1	3	3	15	14
16	12:50:27	N47	4366	1	105	24,76	207,42	144.27	316,97	37					
16	12:50:27				105	24.75	207,86	C.....CAACA.CAACAA.AACAAC			1	3	3	19	17
16	12:50:26				105	24.87	136.23	AACA..A.CAACAAC			0	3	3	15	12
17	12:50:31	N47	4366	1	105	24.69	207,95	154.21	316,88	37					
17	12:50:30				104	24.69	208,21	ACA.CAACAACAACAA.AAC			1	3	3	20	18
17	12:50:30				104	24.81	135.88	CAACAACAACAACAA			1	3	3	15	15
18	12:50:35	N47	4366	1	104	24.62	208,39	159.18	316,79	37					
18	12:50:34				104	24.69	207,60	A.C.....C.....C.A			0	3	3	17	12
18	12:50:34				104	24.75	135.26	AACAACAACAA.AA			1	3	2	14	13
19	12:50:39	N47	4366	1	104	24.56	208,56	139.57	319.09	37					
19	12:50:38				104	24.50	208.74	ACAACAACAACAA.AACAA			1	3	3	19	18
19	12:50:38				104	24.62	134.47	ACAACAA.AACA			0	3	2	12	11
20	12:50:43	N47	4366	1	104	24,50	208,92	147.20	319,84	37					
20	12:50:42				103	24,50	209,36	CAACA.CAACAACAACAACAAC			1	3	3	22	21
20	12:50:42				103	24.62	134.21	AAC.ACAACAA..AC			0	3	3	15	12
21	12:50:47	N47	4366	1	103	24,44	209,36	154.45	318,69	37					
21	12:50:46				103	24.44	209,44	CAACAACA.CA.CAACA.CAA			1	3	3	21	18
21	12:50:45				103	24.56	134.56	CA.CAACA			0	3	2	8	7
22	12:50:51	N47	4366	1	103	24.37	209,79	154.45	318,69	37					
22	12:50:50				0	24.37	209.27	AA.A......A.AA....AAC.A..ACA			0	3	1	28	13
23	12:50:54	N47	4366	1		24.31	209,97	142.76	322.00	37					
23	12:50:54				102	24.31	209.71	ACAAC.A.AAC...AAC..C			1	3	3	20	13
24	12:50:58	N47	4366	1	102	24.25	210,23	135.70	323,43	37					
24	12:50:58				102	24.25	210,67	A...CAACAACAACA.CAA			1	3	3	15	14
24	12:50:57				0	24.37	132.89	AA.AA..A			0	3	0	8	5
25	12:51: 2	N47	4366	1	102	24,19	210,67	147.70	321,77	37					
25	12:51: 2				102	24.25	210.85	AACAACAACAACAACAACAACA			1	3	3	22	22
26	12:51: 6	N47	4366	1	102	24.12	211,11	149.90	320,71	37					
26	12:51: 6				102	24.19	211.55	AA.AACAACA.CAACAACAA			1	3	3	20	18

FIGURE 5-7. FLIGHT HISTORY LISTING

SCAN	TIME	ACID	RBC	C	ALT	RANGE	AZIMUTH	VELOCITY	DIRECTION	FIRM	W/S	VA	VC	RUN	HIT
16	12:50:27	N48	4370	1	100	22.81	222.89	214.71	140.31	37					
16	12:50:27				100	22.87	222.80	C.ACAAC.ACAACAAC			1	3	3	16	14
17	12:50:31	N48	4370	1	100	22.87	222.19	216.97	139.60	37					
17	12:50:31				0	22.94	222.28	ADAADAADAAD			0	3	0	11	11
18	12:50:35	N48	4370	1		22.94	221.66	219.66	140.19	37					
18	12:50:35				0	22.94	221.66	AD.ADA.DAA			0	3	0	10	8
19	12:50:39	N48	4370	1		22.94	221.04	219.66	140.19	37					
19	12:50:38				0	23.00	221.22	D.ADAADAADA			0	3	0	11	10
20	12:50:43	N48	4370	1		23.00	220.43	217.43	140.91	37					
20	12:50:42				0	23.00	220.43	DAADA.DAADAA.A			0	3	0	14	12
21	12:50:47	N48	4370	1		23.00	219.81	219.66	140.19	37					
21	12:50:46				0	23.06	220.08	ADAADAAD			0	3	0	8	8
22	12:50:51	N48	4370	1		23.06	219.29	217.43	140.91	37					
23	12:50:55	N48	4370	0	CST	23.12	218.76	217.43	140.91	36					
23	12:50:54				0	23.19	218.94	AADAADA			0	3	0	7	7
24	12:50:59	N48	4370	1		23.19	218.14	217.43	140.91	36					
25	12:51: 2	N48	4370	0	CST	23.25	217.62	217.43	140.91	35					
26	12:51: 6	N48	4370	0	CST	23.31	217.09	217.43	140.91	34					
27	12:51:10	N48	4370	0	CST	23.37	216.47	217.43	140.91	33					
28	12:51:14	N48	4370	0	CST	23.37	215.95	217.43	140.91	32					
28	12:51:14				0	23.44	216.21	ADAADAADAAD.ADAAD			1	3	0	17	16
29	12:51:18	N48	4370	0	CST	23.46	215.51	217.43	140.91	34					
29	12:51:18				0	23.56	215.68	ADAA.AADAADA.DA.D			1	3	0	17	14
30	12:51:22	N48	4370	0	CST	23.56	214.98	217.43	140.91	36					
31	12:51:26	N48	4370	0	CST	23.62	214.45	217.43	140.91	35					
31	12:51:26				0	23.69	215.24	AF...AAEA.EAAEA.E			0	3	0	12	10
32	12:51:30	N48	4370	0	CST	23.69	214.10	217.43	140.91	35					
32	12:51:30				0	23.75	213.57	CA.CAAU.AUAAUA.U.AUAA			1	2	0	21	17

FIGURE 5-7. FLIGHT HISTORY LISTING (CONTINUED)

ARTS III WIDENED AZIMUTH WINDOW PROGRAM DATE 2 SEP PAGE 0021
SUBSYSTEM 1 SCAN 19 OWN CODE 4370

CODE	TIME	RANGE	AZIMUTH	ALTITUDE		TBA	DAZ	RANGE	BEARING	RUN	HIT
4366	13124148.953	24.5625	208.477	104(	1.7116)	47.461	-13.975	5.9953	141.684	21	19
										ACAACAAC.ACAACA.CAACA	
4370	13124149.195	22.8750	222.451	100(	1.6458)	.000	.000	.0000	UNDEFINED	13	13
										AAUAAUAAUAAUA	

(a)

ARTS III WIDENED AZIMUTH WINDOW PROGRAM DATE 2 SEP PAGE 0023
SUBSYSTEM 1 SCAN 21 OWN CODE 4370

CODE	TIME	RANGE	AZIMUTH	ALTITUDE		TBA	DAZ	RANGE	BEARING	RUN	HIT
4366	13124156.820	24.5000	209.180	104(	1.7116)	41.568	-11.953	5.1663	142.654	22	22
										AACAACAACAACAACAACAACA	
4370	13124156.937	22.9375	221.133	100(	1.6458)	.000	.000	.0000	UNDEFINED	11	11
										ADAADAADAAD	

(b)

FIGURE 5-8. ARTS III WIDENED AZIMUTH WINDOW PROGRAM OUTPUT

```
LCAS QUICK LOOK PROGRAM                                                              DATE 14 DEC 1976    PAGE    0008
RADAR/TARGET LISTING

         HIT 18 BCT393557260.4US CACAACA SCP22.770S SCN   0 PRP1805US 1885 2295 2858 2235 1845 1905 3128
         HIT 23 BCT395745319.1US CACACACA SCP 7.863S SCN   0 PRP2506US
         HIT 14 BCT396487416.7US AAAAAAAA SCP 3.945S SCN   0 PRP3343US

ASR4     HIT 11 BCT396400781.5US AACAACAA SCP 3.923S SCN  28 PRP2625US
SLS1076/ 287. 598 NIN 119 0AL 10200FT AWN228.81 ACH143.00 RID B
TARGETS FOR SCAN  28 RID B    TID  BCD NRP      TOA        DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---      ---        ---      --- ---- ----          ----
                                1 2726  14   47.310US -10.38    34600                  12:50:23.9
                                2 1635  17   48.860US  12.09     8200                  12:50:24.1
                                3 4366  15   54.540US -15.95    10700   64             12:50:23.8

TVAN     HIT 35 BCT397259852.0US AACAACAA SCP 3.990S SCN  81 PRP3999US
SLS 764/ 137. 599 NIN  95 0AL 10200FT AWN137.59 ACH143.00 RID G
TARGETS FOR SCAN  81 RID G    TID  BCD NRP      TOA        DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---      ---        ---      --- ---- ----          ----
                                1 1635  19    1.440US    8.94     8200                  12:50:25.0
                                2 2726   7   65.910US    4.05    34600                  12:50:24.9
                                3 4366   7   83.260US    8.34    10700   51             12:50:25.0
         HIT 12 BCT400427199.0US AAAAAAAA SCP 3.940S SCN   0 PRP3343US

ASR4     HIT 11 BCT400323677.0US AACAACAA SCP 3.923S SCN  29 PRP2625US
SLS1093/ 284. 599 NIN 116 0AL 10200FT AWN227.59 ACH143.26 RID B
TARGETS FOR SCAN  29 RID B    TID  BCD NRP      TOA        DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---      ---        ---      --- ---- ----          ----
                               √1 2726   9   48.840US -10.43    34600                  12:50:27.8
                               √2 4366  16   51.590US -14.76    10700   64     1       12:50:27.8
                                3 1635  17   51.490US  11.43     8200                  12:50:28.1
                                4 4366   9   51.770US  -6.35    10700                  12:50:27.9

TVAN     HIT 38 BCT401259353.9US AACAACAA SCP 4.000S SCN  82 PRP3999US
SLS 827/  88. 597 NIN  95 0AL 10200FT AWN137.98 ACH143.35 RID G
            INTERNAL                                 TIE-BREAKER
              CLOCK                                   DI,XC,XA   PREDICTED TIME UNTIL ALARM (SEC)       RADAR      THREAT
GTRN  BCD     (SEC)    OTHER ALT     OWN ALT        OTHER  OWN        TAU0     TAU1     TAU2    TAU2P       BITS      STATUS
----  ---   ---------  ---------     -------        -----  ---        ----     ----     ----    -----       -----     ------
   1 4366    401.689      10700        10200          000  010      38.258   38.258   -1.863   -1.863       0001          21
                                                    NO TURN    MAXIMUM RATE 2000 FT/MIN UP

TARGETS FOR SCAN  82 RID G    TID  BCD NRP      TOA        DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---      ---        ---      --- ---- ----          ----
                                1 1635  15    1.830US    9.42     8200                  12:50:29.0

OWN      HIT 24 BCT284509061.1US 00000000 SCP 2.499S SCN  75 PRP3000US
SLS    0/    3. 598 NIN  24 0AL 10200FT AWN     .00 ACH143.35 RID K
TARGETS FOR SCAN  75 RID K    TID  BCD NRP      TOA        DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---      ---        ---      --- ---- ----          ----
                                1 4366  16   79.380US     .00    10700    3             12:48:32.1
```

FIGURE 5-9. LCAS QUICK LOOK PROGRAM OUTPUT

```
LCAS QUICK LOOK PROGRAM                                                          DATE 14 DEC 1976    PAGE    0009
RADAR/TARGET LISTING

          HIT 14 BCT402289506.0US CACACACA SCP 9.398S SCN    0 PRP4438US
          HIT 39 BCT403167515.5US ACAACAAC SCP18.773S SCN    0 PRP1823US 1904 2318 2887 2257 1864 1924 3159
            INTERNAL                            TIE-BREAKER
              CLOCK                             DI,XC,XA    PREDICTED TIME UNTIL ALARM (SEC)      RADAR     THREAT
GTRN  BCD     (SEC)    OTHER ALT    OWN ALT    OTHER  OWN      TAU0      TAU1    TAU2    TAU2P     BITS     STATUS
....  ...   ........   ........    .......     .....  ...      ....      ....    ....    .....     .....    ......
   1 4366    404.150      10700      10200       000  010     35.797    35.797   .4.324  .4.324    0001         21
                                               NO TURN    MAXIMUM RATE 2000 FT/MIN UP

OWN     HIT 24 BCT401758965.8US 00000000 SCP 2.499S SCN  76 PRP3000US
SLS   0/   4. 597 NIN  24 OAL 10200FT AWN     .00 ACH143.35 RID K
TARGETS FOR SCAN  76 RID K    TID  BCD NRP      TOA         DAZ      TAL LTRN GTRN          TIME
                              ...  ... ...      ...         ...      ... .... ....          ....
                                1 2621   7   70.610US       .00    42800                 12:50:29.4
                                2 6413  12   74.850US       .00     8200                 12:50:29.4
                                3 4366  13   76.380US       .00    10600     3           12:50:29.4

ASR4    HIT 10 BCT404251410.3US AACAACAA SCP 3.928S SCN  130 PRP2625US
SLS1086/ 275. 599 NIN 114 OAL 10200FT AWN227.70 ACH143.35 RID B
TARGETS FOR SCAN  30 RID B    TID  BCD NRP      TOA         DAZ      TAL LTRN GTRN          TIME
                              ...  ... ...      ...         ...      ... .... ....          ....
                              V 1 4366  20   48.610US    .14.38    10600    64    1      12:50:31.7
                                2 4366   8   48.790US     .5.86    10600                 12:50:31.8
                                3 2726  10   50.750US     .8.89   ******                 12:50:31.8
                                4 1635  13   54.060US     12.01   ******                 12:50:32.0
          HIT 34 BCT404406695.9US CAACAACA SCP18.711S SCN    0 PRP3222US

TVAN    HIT 28 BCT405234670.4US AACAACAA SCP 3.975S SCN  83 PRP3999US
SLS 855/  82. 599 NIN  95 OAL 10200FT AWN137.72 ACH143.35 RID G
   1 4366    406.649      10600      10200       000  010     32.651    32.651   .7.222  .7.222    0001         21
                                               NO TURN    MAXIMUM RATE 2000 FT/MIN UP

TARGETS FOR SCAN  83 RID G    TID  BCD NRP      TOA         DAZ      TAL LTRN GTRN          TIME
                              ...  ... ...      ...         ...      ... .... ....          ....
                                1 1635  18    2.260US      7.83     8200                 12:50:32.9
                                2 1635   7    2.400US     13.35     8200                 12:50:33.0
                                3 2521  13   60.460US      5.63    33800                 12:50:32.9
                                4 6413   7   72.110US      6.21   ******                 12:50:32.9
                                5 4366  13   73.540US      4.84    10600    65           12:50:32.9

OWN     HIT 24 BCT404239129.9US 00000000 SCP 2.499S SCN  77 PRP3000US
SLS   0/   6. 597 NIN  24 OAL 10200FT AWN     .00 ACH143.61 RID K
TARGETS FOR SCAN  77 RID K    TID  BCD NRP      TOA         DAZ      TAL LTRN GTRN          TIME
                              ...  ... ...      ...         ...      ... .... ....          ....
                                1 4366  22   73.370US       .00    10600     3    1      12:50:31.8
          HIT 12 BCT406994370.6US ACACACAC SCP 4.705S SCN    0 PRP4438US
          HIT 18 BCT407522035.4US CACACACA SCP11.777S SCN    0 PRP2506US
```

FIGURE 5-9. (CONTINUED)

Tables 5-17a through 5-17f enumerate just six of the runs that were analyzed and contain entries of selected ASR-4 data of OTHER as processed by BCAS detailed processing program and the widened azimuth window program on a scan for scan basis. Information in the table for BCAS includes scan number, DAZ, number of replies, TOA, altitude difference, local track number and time. Data from the widened azimuth window program consists of DAZ, TOA, range, scan number, run length, number of transponder repies and time.

It may be seen in the table entries that DAZ and TOA values of OWN for BCAS and ARTS III are within acceptable tolerances, considering the inaccuracies associated with ARTS III positioning of OWN and OTHER.

Tables 5-17a and 5-17b contain a number of false reports of OTHER (i.e., target reports for a given scan, the second entry for the scans identified by letter F) that were detected by BCAS but were not evidenced in the widened azimuth window program listing.

Further inspection of the detailed processing listings (Figure 5-10) with the flight history listings, (Figure 5-7) also shows reports for OTHER on the same scans (i.e., 2 target reports from the same scan). However, ARTS III (see Figure 5-7) indicates, for example, that OTHER is at an azimuth of 207.86°, with a false target report for OTHER appearing at 136.23° which is well outside the ±18° widened azimuth window. BCAS in turn detects the false target (see Figure 5-9) but states that it is within the ±18° widened azimuth window. Additional tests in strong multipath and a check on omni antenna radiating pattern alignment with the main beam pattern may explain false target presence in BCAS and ARTS III measurements.

Analysis of data reduction output listings indicated that aircraft appearing within ±15.0° of OWN as defined by ARTS III were all accountable for with respect to those aircraft detected by BCAS when locked to the ASR-4 radar. Acutally there were more aircraft detected by ARTS III but these additional aircraft were outside of BCAS's volume of interest due to either altitude or range differences. The converse of this was also true, viz., there were

LCAS DETAILED PROCESSING PROGRAM
RADAR/TARGET LISTING

DATE 22 JUN 1977 PAGE 0016

GTRN	BCD	INTERNAL CLOCK (SEC)	OTHER ALT	OWN ALT	TIE-BREAKER D1,XC,XA OTHER	TIE-BREAKER D1,XC,XA OWN	PREDICTED TIME UNTIL ALARM (SEC) TAU0	TAU1	TAU2	TAU2P	RADAR BITS	THREAT STATUS
1	4216	172.426	8800	10000	000	000	130.729	130.729	-221.025	-155.711	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	172.426	8800	10000	000	000	-20.212	-20.212	-41.717	-41.717	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	172.436	8800	10000	000	000	-18.597	-18.597	-39.883	-39.883	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	172.436	8800	10000	000	000	-13.750	-13.750	-36.082	-36.082	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
1	4216	174.717	8800	10000	000	000	130.738	130.738	-223.305	-155.702	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	174.717	8800	10000	000	000	-22.502	-22.502	-44.007	-44.007	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	174.726	8800	10000	000	000	-20.887	-20.887	-42.173	-42.173	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	174.726	8800	10000	000	000	-16.041	-16.041	-38.372	-38.372	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
5	4216	174.736	8800	10000	000	000	130.710	130.710	58.793	58.793	1000	00
							MAXIMUM RATE 2000 FT/MIN DOWN					
1	4216	177.206	8800	10000	000	000	130.738	130.738	-195.614	-155.702	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	177.216	8800	10000	000	000	-25.002	-25.002	-46.506	-46.506	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	177.216	8800	10000	000	000	-23.377	-23.377	-44.663	-44.663	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	177.216	8800	10000	000	000	-18.530	-18.530	-40.862	-40.862	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
5	4216	177.225	8800	10000	000	000	116.075	116.075	41.460	41.460	1000	00
							MAXIMUM RATE 2000 FT/MIN DOWN					

FIGURE 5-10. MULTIPLE GLOBAL TRACKS OF OTHER

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS

	SCAN #		DAZ	NRP	TOA	Alt. Diff.	LTRN	GLBTR	DAZ	TOA	RANGE	SCAN #	TIME
F*	27	21	-15.80	15	57.54	+600'	64	12/50/19.9	-17.05	58.09	7.34	19	12/50/19.19
		13	-8.41	9									
	28	17	-15.95	15	54.54	+500'	64	12/50/23.8	-16.17	54.97	6.96	20	12/50/23.12
		14											
F	29	17	-14.76	16	51.59	+500'	64	12/50/27.8	-14.94	51.43	6.45	21	12/50/27.05
		12	-6.35	9									
F	30	18	-14.38	20	48.61	+400'	64	12/50/35.6	-14.06	48.31	6.07	22	12/50/30.98
		15											
	31	12	-15.92	15	45.65	+400'	64	12/50/35.6	-14.06	48.31	6.07	23	12/50/34.91
		13											
F	32	18	-12.41	20	42.55	+400'	66	12/50/39.6	-12.48	42.39	5.36	24	12/50/38.85
		11											
F	33	21	-12.40	18	39.69	+300'	66	12/50/43.5	-11.07	38.98	4.81	25	12/50/42.79
		12	-2.96	6									
F	34	18	-14.67	12	36.83	+300'	66	12/50/47.4	-10.64	36.91	4.60	26	12/50/46.72
		7	-2.05	7									

*F false target (i.e. multiple target of OWN) detected by BCAS.

11/18 RUN 1

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS (CONTINUED)

	SCAN #	DAZ	NEP	TOA	LTRN	TIME	DAZ	TOA	RANGE	SCAN #	RL	HITS	TIME
	4	-15.60	9	53.82	1	13/24/46.8	-15.99	53.89	6.85	17	18	17	13/24/41.1
	5	-14.43	6	50.91	1	13/24/45.8	-14.41	49.52	6.20	18	19	14	13/24/45.0
F	6	-14.88	15	48.05	1	13/24/49.7	-13.98	47.46	6.00	19	21	19	13/24/49.0
		-5.39	8										
	7	-13.04	15	45.11	1	13/24/53.6	-13.10	44.79	5.63	20	19	18	13/24/56.8
	8	-11.89	18	42.12	1	13/24/57.6	-11.95	41.57	5.17	21	22	22	13/24/56.8
F	9	-11.91	12	39.08	1	13/25/1.5	-11.16	39.12	4.83	22	20	18	13/25/0.8
		-12.12	11	45.24									
	10	-10.31	17	36.07	1	13/25/5.4	-10.55	36.10	4.53	23	19	18	13/25/4.7
		lost lock on ASR-4											
	2	-9.03	19	14.80	28	13/25/33.0	-4.48	16.83	2.16	30	19	12	13/25/32.6
F	3	-4.42	18	11.54	33	13/25/37.0	-3.78	14.37	1.89	31	19	16	13/25/36.3
		-9.29	9	11.83									
	4	-5.15	14	8.53	28	13/25/40.9	-3.34	12.73	1.81	32	18	14	13/25/40.2
	5	-3.71	15	5.48	28	13/25/44.8	no target report for OWN this scan						
	6	-0.42	14	2.17	28	13/25/48.8	no target report for OTHER this scan						

11/18 RUN 3

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS (CONTINUED)

SCAN #	DAZ	NRP	TOA	LTRN	TIME	DAZ	TOA	RANGE	SCAN #	RL	HITS	TIME
7	-14.18	17	8.33	98	13/13/42.5	-14.24	8.79	3.05	9	22	15	13/13/42.2
8	-13.51	13	8.48	98	13/13/46.4	-14.06	8.78	3.05	10	21	15	13/13/46.2
9	-13.05	12	8.55	98	13/13/50.4	-13.80	8.99	3.02	11	17	16	13/13/50.1
10	-13.00	12	8.33	98	13/13/54.3	-13.01	8.38	2.92	12	16	15	13/13/54.0
11	-12.54	19	8.00	98	13/13/58.2	-12.39	8.35	2.79	13	22	20	13/13/57.9
12	-12.29	19	7.63	98	13/14/02.1	-11.69	7.64	2.74	14	25	23	13/14/01.9
13	-11.80	18	7.20	98	13/14/06.1	-11.60	7.74	2.75	15	22	22	13/14/05.8
14	-11.05	11	6.85	98	13/14/10.0	-10.72	6.97	2.63	16	16	16	13/14/0.97
15	-11.28	18	6.50	98	13/14/13.9	-11.16	7.60	2.73	17	23	23	13/14/13.6
16	-9.45	14	5.98	98	13/14/17.9	-10.20	6.92	2.56	18	27	20	13/14/17.5
17	-8.92	18	5.60	98	13/14/21.8	-9.316	6.17	2.44	19	21	18	13/14/21.5
18	-8.50	20	5.26	98	13/14/25.8	-8.26	5.20	2.28	20	21	19	13/14/25.4

11/17 RUN 3

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS (CONTINUED)

SCAN #	DAZ	NRP	TOA	LTRN	TIME	DAZ	TOA	RANGE	SCAN #	RL	HITS	TIME
4	1.64	6	41.66	105	13/27/07.4	0.70	41.79	3.39	57	17	12	13/27/07.1
5	0.54	9	43.02	105	13/27/11.3	-0.09	43.27	3.50	58	15	10	13/27/11.0
6	0.82	13	44.28	105	13/27/15.3	0.79	44.89	3.64	59	18	11	13/27/15.0
7	0.13	15	45.55	105	13/27/19.2	-0.26	45.60	3.69	60	27	18	13/27/18.9
8	0.32	16	46.87	105	13/27/23.1	0.79	47.21	3.83	61	19	16	13/27/22.8
9	0.56	14	48.07	105	13/27/27.1	0.35	48.70	3.95	62	21	14	13/27/26.7
10	0.25	17	49.20	105	13/27/31.0	0.35	50.25	4.07	63	21	16	13/27/30.7
11	-0.19	20	50.35	105	13/27/34.9	0.00	50.24	4.07	64	27	18	13/27/34.6

11/17 RUN 4

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS (CONTINUED)

SCAN #	DAZ	NRP	TOA	LTRN	TIME	DAZ	TOA	RANGE	SCAN #	RL	HITS	TIME
16	-6.80	13	6.97	112	13/30/50.9	-6.86	6.87	2.11	6	15	14	13/30/50.6
17	-6.05	15	6.42	112	13/30/54.9	-6.59	6.78	2.04	7	17	14	13/30/54.5
18	-6.22	14	5.75	112	13/30/58.8	-6.06	6.09	1.92	8	18	14	13/30/58.4
19	-5.88	16	5.00	112	13/31/02.7	-5.36	4.97	1.80	9	21	17	13/31/02.4
20	-5.47	19	4.35	112	13/31/06.7	-4.92	4.42	1.72	10	20	14	13/31/06.3
21	-4.97	17	3.65	112	13/31/10.6	-5.01	4.58	1.74	11	24	18	13/31/10.2
22	-4.06	12	2.98	112	13/31/14.5	-4.66	4.00	1.71	12	21	12	13/31/14.1
23						-4.22	3.45	1.62	13	19	14	13/31/18.0
24	-4.24	18	1.89	112	13/31/22.4	-5.01	4.56	1.80	14	26	15	13/31/22.0
25	-2.62	12	1.41	112	13/31/26.3	-4.31	3.78	1.61	15	25	16	13/31/25.9
26	-2.98	12	1.21	112	13/31/30.2	-3.34	2.67	1.37	16	20	17	13/31/29.9

11/17 RUN 5

TABLE 5-17. COMPARATIVE DATA ASR-4 VS. BCAS (CONTINUED)

SCAN #	DAZ	NRP	TOA	LTRN	TIME	DAZ	TOA	RANGE	SCAN #	RL	HITS	TIME
3	3.74	8	20.24	119	13/49/21.9	3.52	20.81	1.93	49	19	13	13/49/21.4
4	5.14	10	21.32	119	13/49/25.9	4.31	24.07	2.27	50	14	11	13/49/25.5
5	3.82	16	22.49	119	13/49/29.8	4.13	23.86	2.24	51	15	14	13/49/29.4
6	4.17	15	23.58	119	13/49/33.8	3.96	24.31	2.25	52	13	13	13/49/33.4
7	3.24	20	24.71	119	13/49/37.7	3.34	24.87	2.21	53	18	17	13/49/37.3

11/17 RUN 7

no false alarms detected by BCAS other than the multiple false targets of OTHER that have previously been discussed. Assessments of the output listings did not detect any missed tracks. However, there were many multiple global tracks of OTHER (see Figure 5-10) that appeared throughout the test runs. These multiple global tracks could have been generated for a variety of reasons. A faulty or marginal transponder could be the cause of false targets/false tracks. The aforementioned false targets of OTHER resulted in multiple global tracks. Perhaps the algorithm used in the software is heavily oriented to negating missed alarms/missed tracks and thus may inadvertently be conducive to false targets/false tracks. In any such event, additional testing is recommended in order to investigate OTHER's false target anomaly and also to investigate the predominance of false tracks.

5.15 SYNCHRONOUS GARBLE

Synchronous garble flight testing performed on the passive BCAS consisted of measuring both synchronous and self garble interference with the system. The tests involved two aircraft and a fixed target atop a fire tower. The observing aircraft, referred to as OWN, maintained a constant radius in flying a circular pattern about the fixed target. The second aircraft flew inbound and outbound radials inside the orbit along the center line of the antenna beam passing through the fixed ground target.

Self garble interference with both targets on the radial regardless of their radial separation distance is observed by OWN when the major axis of the ellipsoid coincides with the line of position on the radial; all three targets are within the antenna's main beam. Synchronous garble interference is observed when the fixed transponder reply and the reply from the aircraft flying the radial are within $\pm 20.3 \mu sec$ separation; the OWN is outside the antenna main beam but within the widened azimuth window.

By definition, self garble interference is observed when the BCAS itself, is replying to a ground interrogator, during the 20.3μ second interval and the intruder replies arrive in coincidence.

Synchronous garble is generic to ATCRBS and is caused by interference of two aircraft replying in coincidence with their message length occurring at the same time as the receiver and OWN aircraft is taking a measurement. The difference in both signal arrivals is within $\pm 20.3 \mu sec$ interval.

BCAS synchronous garble tests were conducted at NAFEC. Two aircraft and the fire tower at MIZPAH were employed. One aircraft was instructed to fly outbound and inbound radials to the ASR-5 on a 293.6° azimuth heading. At a distance of 12.3 nautical miles from the radar, the aircraft was positioned over the stable transponder affixed to the fire tower at MIZPAH. See Figure 5-11. While this aircraft flew a prescribed radial pattern, the other designated air craft would fly the circular pattern about the fire tower with the radius designated as five nautical miles.

Beacon codes were assigned to the three targets of interest. For the radial aircraft code assignment was 0302. The orbiting aircraft code assignment was 301, while the MIZPAH tower transponder was designated 1270.

Subjective evaluation of the flight testing can be accomplished with data reduction software at a later date.

Two examples of pictorial representation that can be employed are a plot depicting the receipt of the targets at MIZPAH and radial aircraft as missing, garbled, or present (received), Figure 5-13.

Another source is listings Figure 5-12,and Figure 5-13 that delineate the targets of interest by scan, beacon code, TOA, DAZ, and number of replies. The listings also indicate whether the "X" or "SPI" pulses in the reply train were set inadvertently, Figure 5-12.

5.16 EXPERIMENTAL BCAS THREAT LOGIC

5.16.1 Threat Logic Description

The threat logic of the experimental BCAS is more complex than ANTC-117 logic specified for independent airborne collision avoidance systems. The basic threat criterion in ANTC-117 is TAU, the ratio

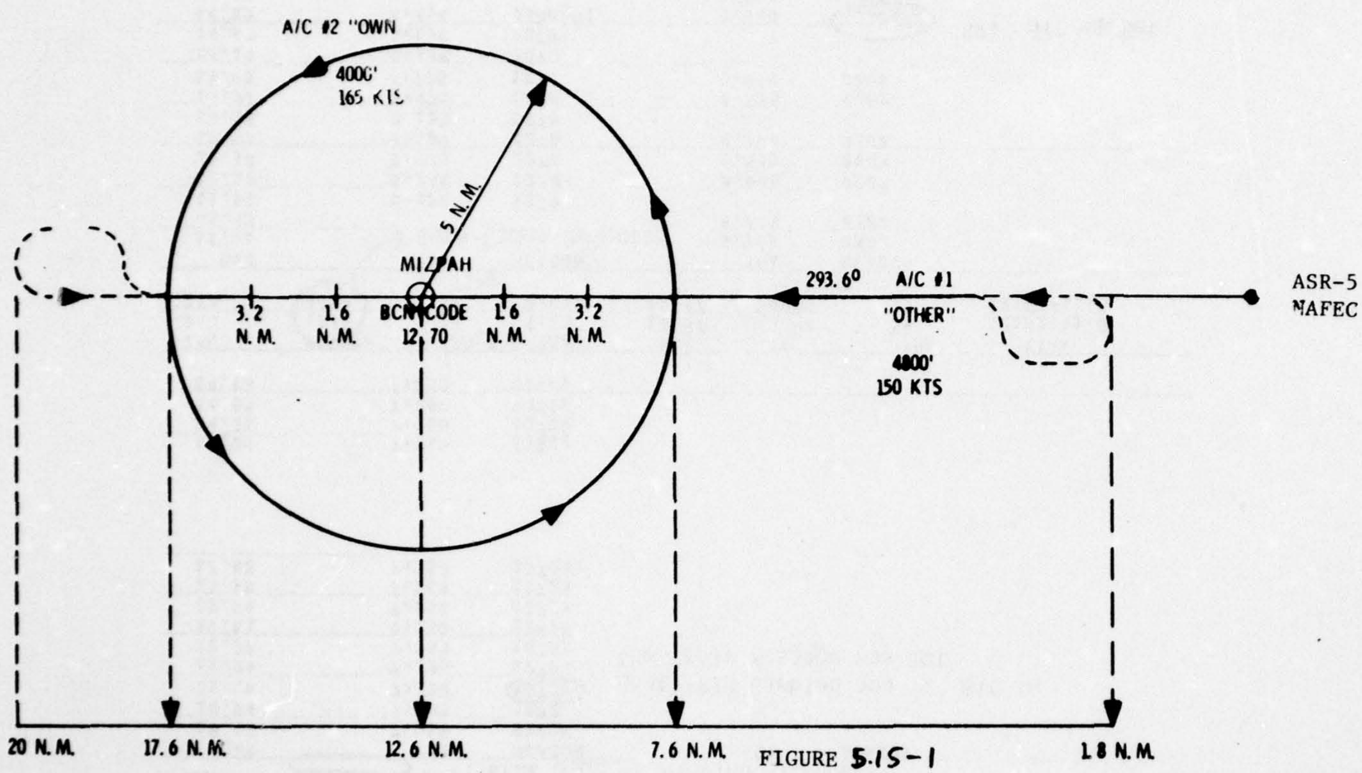


FIGURE 5-11. SYNCHRONOUS GARBLE FLIGHT TEST PATTERN

SCAN	BEACON	NREPLY	TOA	DAZ	TAL	LTRN	TIME
212	1372(G)	20	7.250	12.43	4600	55	12:51: 6.6

0302 is Missing

	FIRST		SECOND	
DAZ	TOA	BEACON	TOA	BEACON
10.49	7.250	0302X		
10.94	7.105	1270		
11.16	7.250	1372X		
11.84	7.105	1272X		
12.29	7.250	1370X		
12.51	7.250	1372X		
12.96	7.250	1372X		
13.18	7.250	1372X		
13.63	7.250	1372X		
13.86	7.250	1372X		
14.31	7.105	1370X		
14.53	7.250	0302X		
14.98	7.250	0302X		

Code 1270 Garbled and "X" Bit in The Reply Message was Set

SCAN	BEACON	NREPLY	TOA	DAZ	TAL	LTRN	TIME
213	1270	14	8.130	13.07	5000	54	12:51:11.3
213	0302	12	8.680	12.47	4900	55	12:51:11.3

Both Codes Detected

	FIRST		SECOND	
DAZ	TOA	BEACON	TOA	BEACON
11.26			8.555	0302
11.48			8.700	0302
11.93	8.120	1270		
12.16	8.265	1270	8.845	0000
12.60	7.975	1270	8.555	0202
12.83	8.120	1270	8.700	0300
13.28	8.120	1270		
13.50	7.975	1270	8.555	0202
13.95	7.975	1270	8.555	0000
14.18	8.120	1270		
14.63	8.120	1270		
14.85	8.410	3330SPI	8.410	3330SPI
15.30			8.700	0302
15.52			8.700	0302

"SPI" Bit is Set

FIGURE 5-12. FLIGHT DATA INFORMATION-SCAN 212

```
202
871  SCAN      BEACON    NREPLY   TOA       DAZ      TAL      LTRN     TIME
853  369       6507      11       10.380    18.33    3500     25       14:26:28.8
872                          FIRST                     SECOND
         DAZ             TOA      BEACON           TOA     BEACON
855   17.45             10.295    6507
855   17.68             10.295    6507
855   18.12             10.295    6507
855   18.35             10.295    6507
855   18.79             10.440    6507
855   19.46             10.440    6507
855   19.91             10.440    4520
202
871  SCAN      BEACON    NREPLY   TOA       DAZ      TAL      LTRN     TIME
853  370       6507      21       10.840    18.37    3500     25       14:26:33.5
872                          FIRST                     SECOND
         DAZ             TOA      BEACON           TOA     BEACON
855   16.45             10.730    6507
855   16.90             10.875    6507
855   17.12             10.730    6507
855   17.57             10.875    6507
855   17.79             10.730    6507
855   18.24             10.730    6507
855   18.46             10.875    6507
855   18.91             10.730    6507
855   19.13             10.730    6507
855   19.58             10.875    6507
855   19.80             10.875    6507
855   20.48             10.875    6507
855   20.92             10.875    6507
855   21.15             10.875    6507
202
871  SCAN      BEACON    NREPLY   TOA       DAZ      TAL      LTRN     TIME
853  371       6507      19       11.400    17.55    3500     25       14:26:38.2
872                          FIRST                     SECOND
         DAZ             TOA      BEACON           TOA     BEACON
855   15.78             11.455    6507
855   16.20             11.310    6507
855   16.45             11.455    6507
855   16.67             11.310    6507
855   17.12             11.310    6507
855   17.34             11.310    6507
855   17.79             11.455    6507
855   18.21             11.455    6507
855   18.68             11.310    6507
```

FIGURE 5-13. FLIGHT DATA INFORMATION-SCAN 369

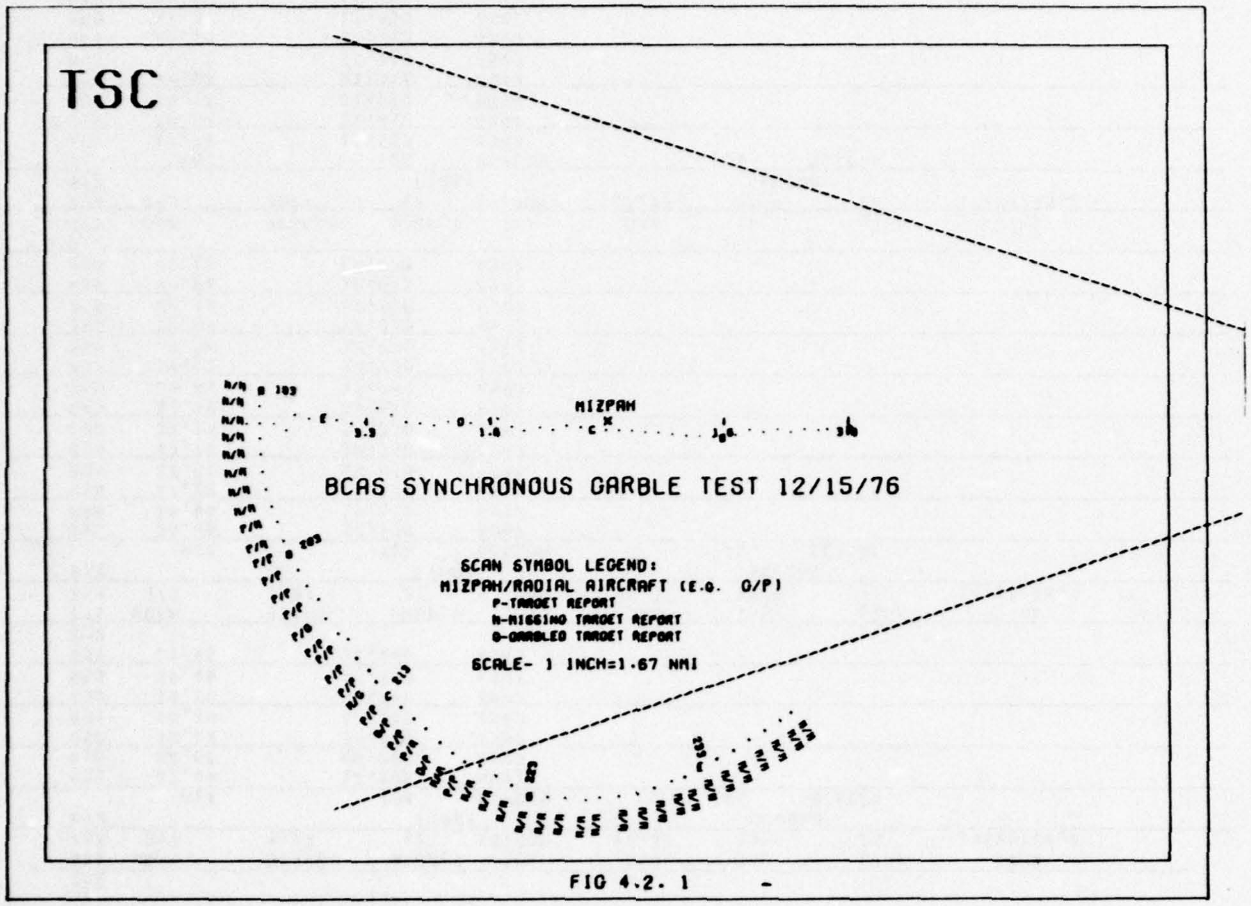


FIGURE 5-14. BCAS SYNCHRONOUS GARBLE TEST LOWER PART

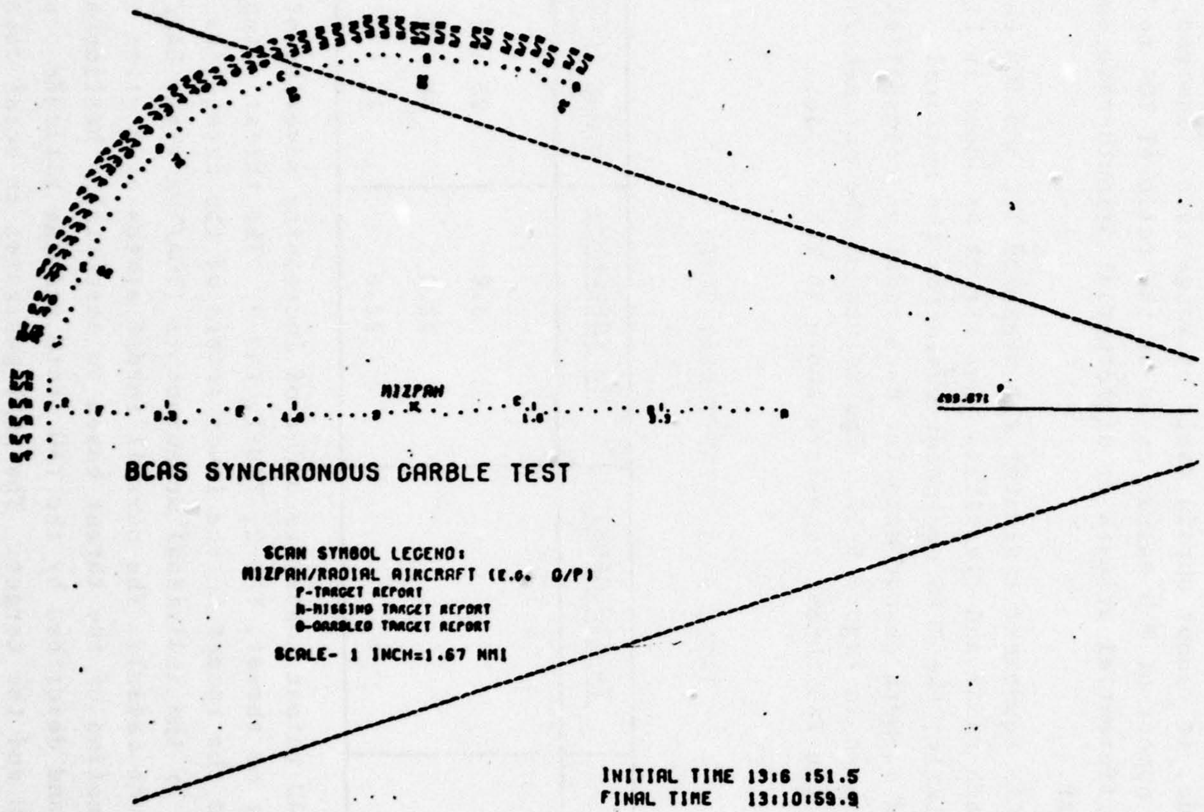


FIGURE 5-15. BCAS SYNCHRONOUS GARBLE TEST UPPER PART

of range to range-rate. When the BCAS is operating in the active mode (transmitting interrogations on 1030 MHz), it can obtain this same TAU. However, when the experimental BCAS is operating in the passive mode, it cannot obtain range or range-rate. Instead, it computes a number of TAU values based on the ratio of TOA to TOA-rate and differential azimuth to differential azimuth-rate for each locked radar.

The BCAS equipment evaluates the measured TOA and TOA change data for each radar and classifies that threat as shown in Figure 5-16. Similarly, the BCAS equipment evaluates the measured azimuth and azimuth change data for each radar and classifies the threat as shown in Figure 5-17. The values of the parameters specifying the TAU threat zones are shown in Table 5.16.1.

TABLE 5-18. TAU THREAT ZONES

TAU ZONE	Tm (SECONDS)	To (SECONDS)	$\frac{1}{\text{SLOPE}}$ (SECONDS)
TAU-0	6.1		
TAU-1		3.0	25 + T
TAU-2		22.0	40 + T
TAU-2P		22.0	40 + T

The TAU threat zones, in order of increasing severity of threat, are no threat, TAU-2, TAU-1, TAU-0. The threat category assigned to the target in the least severe of the categories determined by the individual measurements (TOA/TOA rate, DAZ/DAZ rate for each radar). The overall threat status of a given target is a combination of the threat based on essentially horizontal proximity and described by the TAU state and the altitude separation of OWN and the target. The BCAS generates an octal code for each threat state and outputs the code onto magnetic tape. The set of octal codes is defined in Table 5-19.

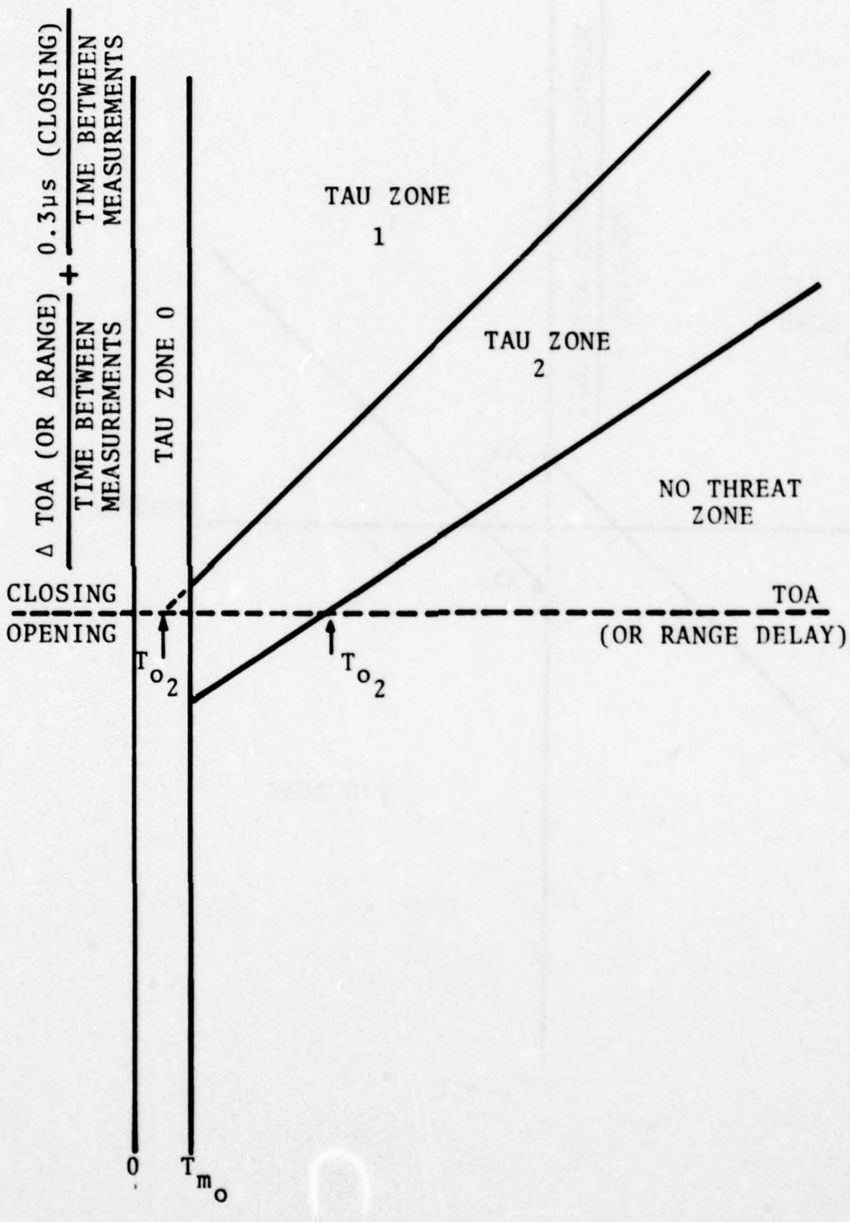


FIGURE 5-16. TOA/TOA-RATE ZONES

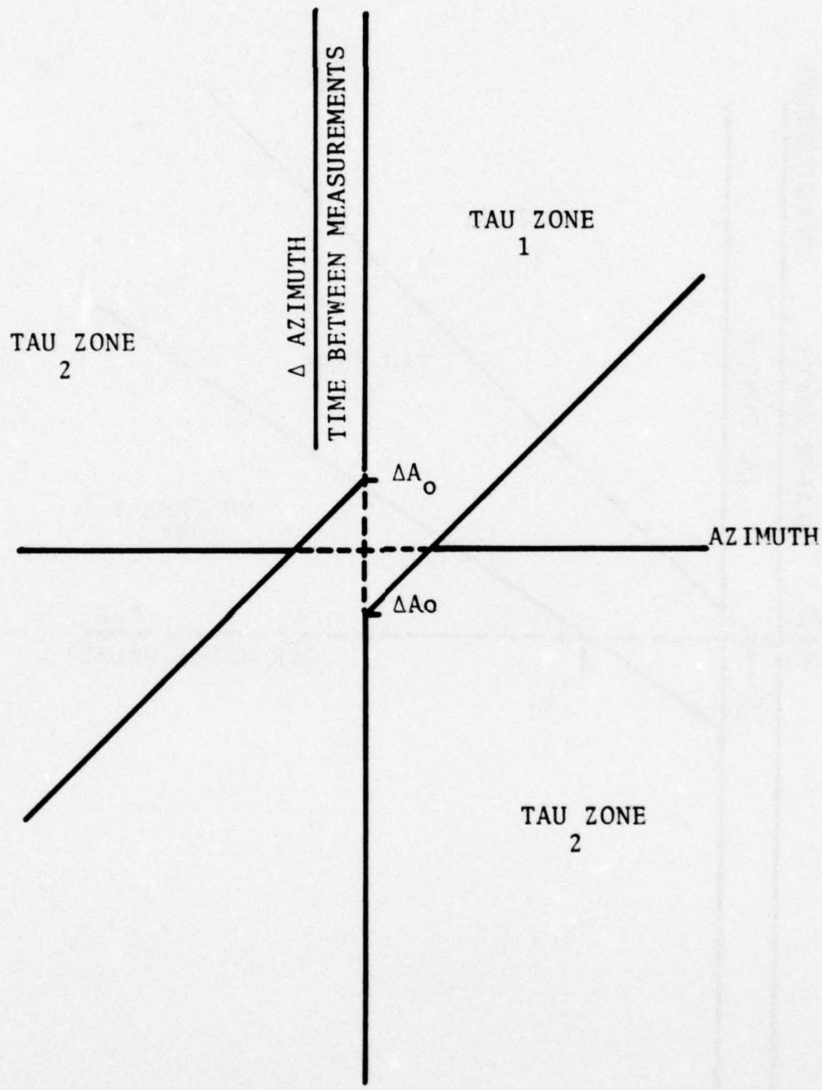


FIGURE 5-17. AZIMUTH/AZIMUTH-RATE ZONES

NOTE: Do not use this figure if largest TOA is less than 6.1 microseconds (0.5 nmi) $\Delta Ao \approx .7°$

TABLE 5-19. THREAT CLASSIFICATION CODE

Octal Code	Meaning (Threat Status)
00	No Threat
02	TAU-1 or TAU-2; 1900' - 3300' below
03	TAU-1 or TAU-2, 1900' - 3300' above
04	TAU-1 or TAU-2, 1400' - 1800' below
05	TAU-1 or TAU-2, 1400' - 1800' above
06	TAU-1 or TAU-2, <1400' below; not co-altitude
07	TAU-1 or TAU-2, <1400' above; not co-altitude
12	TAU-1 or TAU-2, Pred. co-alt; 1900' - 1300' below
13	TAU-1 or TAU-2, Pred. co-alt; 1900' - 1300' above
14	TAU-1 or TAU-2, Pred. co-alt; 1400' - 1800' below
15	TAU-1 or TAU-2, Pred. co-alt; 1400' - 1800' above
16	TAU-1 or TAU-2, pred. co-alt; <1400' below
17	TAU-1 or TAU-2, pred. co-alt; <1400' above
20	TAU-2; Co-altitude below
21	TAU-2; Co-altitude above
22	TAU-2; Same Altitude
30	TAU-1; Co-altitude below
31	TAU-1; Co-altitude above
32	TAU-1; Same altitude

The experimental BCAS system has provision for specifying various combinations of active and passive operation and various choices of antennas. These are determined by specifying what is referred to as the I-code, consisting of 2 digits, of the form $ID_R\ D_A$. The digit D_R may be set to a value from 0 to 3. The BCAS will always interrogate in the active mode unless it is locked to more than D_R ground radars. The octal digit D_A determines antenna selection and the decision whether to initiate active interrogation if a threat is determined to exist. The significance of the D_A code bits is specified in Table 5-20.

TABLE 5-20. INTERROGATOR AND ANTENNA ASSIGNMENTS

D_A	Interrogate on Threat	Antennas Top	Antennas Bottom	
0	0	0	0	- do not interrogate
1	0	0	1	- bottom antenna
2	0	1	0	- top antenna
3	0	1	1	- both antenna
4	1	0	0	- interrogate on threat (however, neither antenna is selected, hence no interrogation)
5	1	0	1	- bottom antenna interrogate on threat
6	1	1	0	- top antenna interrogate on threat
7	1	1	1	- both antennas; interrogate on threat

For the purpose of clarification, examples of possible interrogation modes are given as follows:

I00 - full passive; interrogator always OFF

I33 - full active; forced (both antennas)

I23 - active unless locked on 3 radars; then interrogator is always off

I27 - active unless locked on 3 radars; then interrogator is OFF, but will go active on threat (both antennas)

I17 - active unless locked on 2 or more radars; then interrogator is OFF, but will go active on threat (both antennas)

I13 - active unless locked on 2 or more radars; then interregator is always OFF (both antennas).

NOTE: active interrogation consists of
12 bursts with 3 or 6 millisecond intervals on top antenna
12 bursts with 3 or 6 millisecond intervals on bottom antenna
separated by 18.2 milliseconds between antenna switch-over and 2.5 seconds between the bursts.

5.16.2 Flight Patterns Used for the Threat Logic Tests

The BCAS threat logic was tested in the level flight encounters and in the climb-drive encounters. The latter patterns appeared to be more demanding on the performance of the threat logic, and therefore greater emphasis was given to this test.

Tests were conducted at NAFEC in the vicinity of Sea Isle Vortac by having radar coverage from the test van located at Newport, N.J. and the ASR-4 radar at NAFEC. The layout of the flight test patterns flown are shown in Figure 5-18.

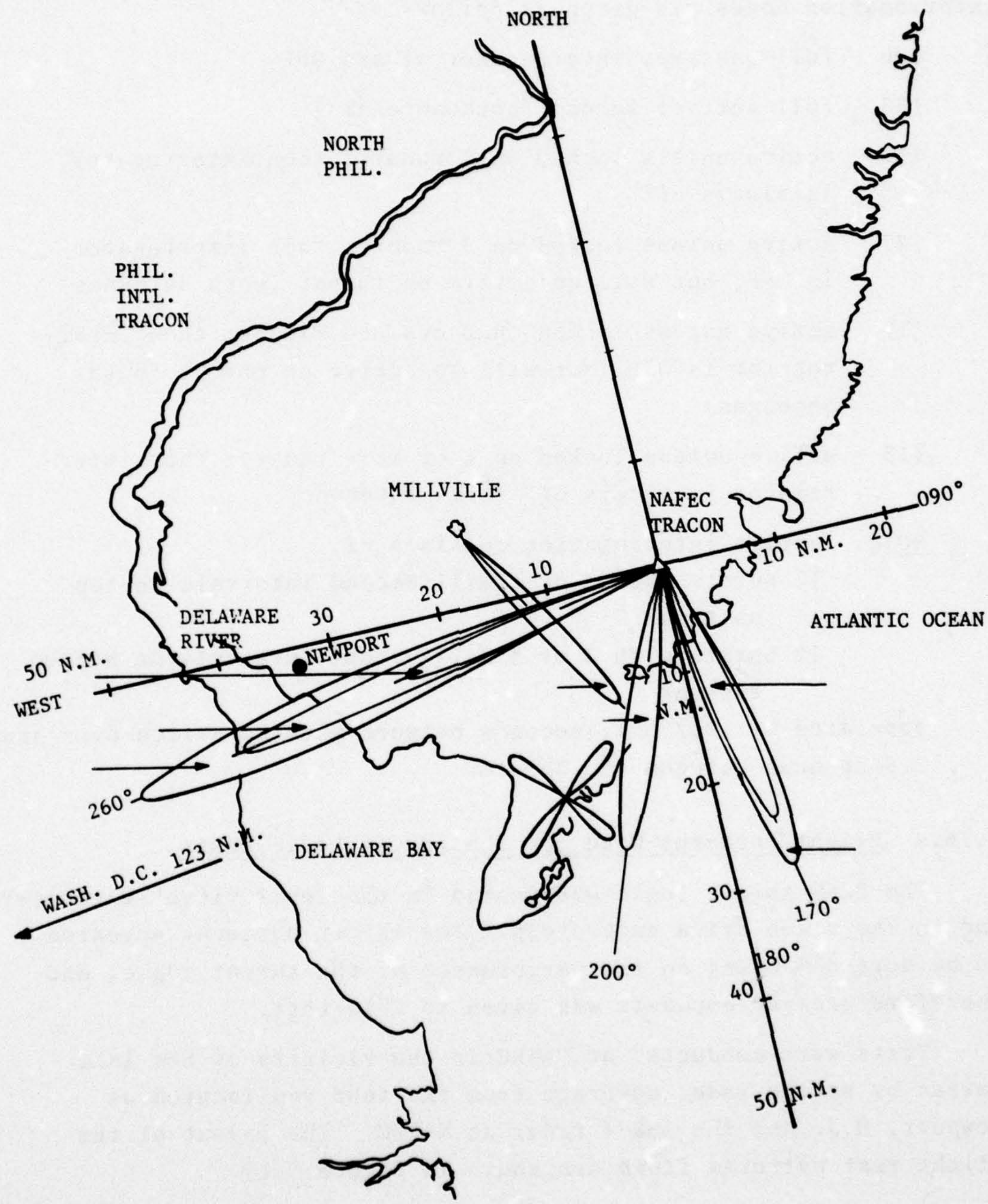
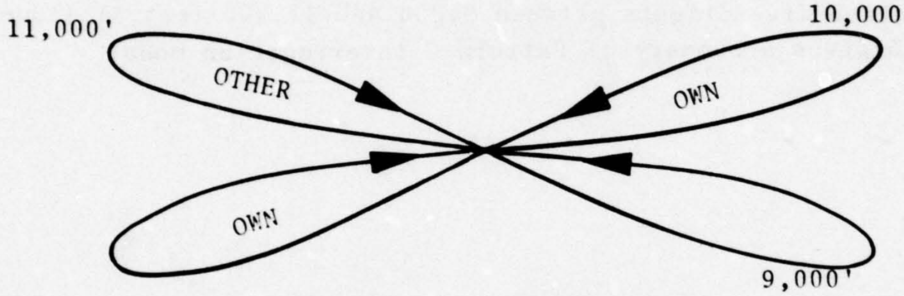


FIGURE 5-18. TEST LAYOUT

Three flight patterns flown between altitudes of 9,000 and 11,000 feet were used in the BCAS test. These are:

Pattern A. In pattern A, the OWN aircraft was repeatedly flying figure eights along 30°/210° and 50°/230° at 10,000 feet altitude (Figure 5-19). Meanwhile, the OTHER performed parallel climb-dive flights between 9,000 and 11,000 feet altitudes.



LEVEL VS. CLIMB-DIVE PARALLEL

FIGURE 5-19. PATTERN A - BCAS EQUIPPED AIRCRAFT (OWN) FLYING LEVEL AND OTHER FLYING IN THE SAME DIRECTION EITHER CLIMBING OR DIVING

Table 5-21 gives a summary of Pattern A maneuvers and interrogation modes used.

TABLE 5-21. PATTERN A INTERROGATION MODE SUMMARY

Test Number	Maneuver	Interrogation Mode
1	D*	I17
2	C	I17
3	D	I33
4	C	I33
5	D	I32
6	C	I32
7	C	I31
8		

*Indication maneuver of OTHER aircraft: D-dive, C-climb

Pattern B. Both the OWN and OTHER aircraft were in climb-dive parallel patterns similar to Pattern A flying along the 30°/210° and 50°/230° figure eights (Figure 5-20).

Table 5-22 gives a summary of the climb-dive maneuvers and interrogation modes used.

Pattern C. In pattern C, OWN aircraft was flying a sequence of figure eights along 300°/120° and 320°/140° at 10,000 feet altitude (Figure 5-21). OTHER performed repeated encounters in parallel climb-dive flights between 9,000 and 11,000 feet altitudes. Table 5-23 gives a summary of Pattern C interrogation mode.

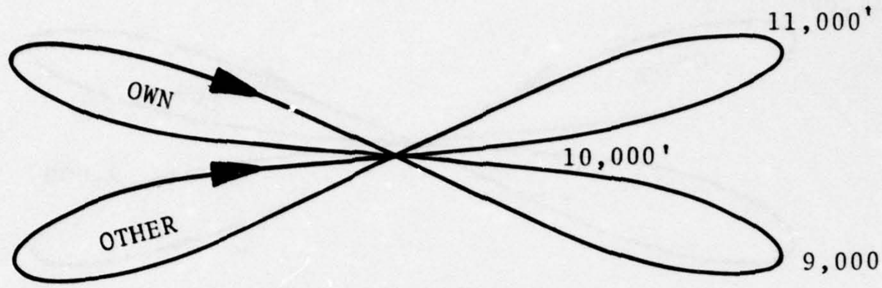
5.16.3 Threat Logic Climb-Dive Test Data Analysis

The twenty-four climb-dive tests were analyzed to assess BCAS adequacy in determining altitude threat zones. Associated BCAS and ARTS III field test tapes were processed to produce

- BCAS Detailed Listings
- Threat Information Listings
- TOA Cal Comp Plots - OWN Interrogator
- TOA and DAZ Comparison Cal Comp Plots (BCAS versus ARTS III).

The BCAS Detailed Processing Program output is described in Section 6. Of particular importance for this analysis is the threat information listing containing Type 7-1 message data (Appendix E). A representative sample of these data is contained in Figures 5-22 - 5-26.

Plots of OWN interrogator TOA were generated for all tests and are shown in Figures 5.16-12 through 5.16-33. During testing, when a threat occurred, OWN's interrogator was activated every



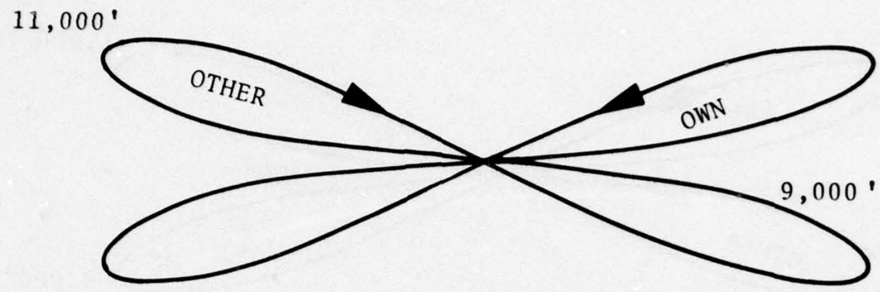
CLIMB & DIVE PARALLEL

FIGURE 5-20. PATTERN B - BOTH AIRCRAFT OWN AND OTHER, CLIMBING AND DIVING IN THE SAME DIRECTION

TABLE 5-22. PATTERN B INTERROGATION MODE SUMMARY

Test Number	Maneuver	Interrogation Mode
9	D-C*	I17
10	C-D	I17
11	D-C	I33
12	C-D	I33
13	D-C	I32
14	C-D	I32
15	D-C	I31
16	C-D	I31

*Indication of OWN-OTHER aircrafts; e.g. D-C; OWN-drive OTHER-climb



LEVEL VS. CLIMB-DIVE HEAD-ON

FIGURE 5-21. PATTERN C - OWN AIRCRAFT FLIES LEVEL AND OTHER FLIES OPPOSITE DIRECTION EITHER CLIMBING OR DIVING

TABLE 5-23. PATTERN C INTERROGATION MODE SUMMARY

Test Number	Maneuver	Interrogation Mode
17	D*	I17
18	C	I17
19	D	I33
20	C	I33
21	D	I32
22	C	I32
23	D	I31
24	C	I31

*Maneuver of OTHER: D-dive, C-climb.

```
LCAS QUICK LOOK PROGRAM                                                          DATE 22 NOV 1976    PAGE     0146
RADAR/TARGET LISTING
           INTERNAL                         TIE-BREAKER
            CLOCK                             D1,XC,XA     PREDICTED TIME UNTIL ALARM (SEC)       RADAR     THREAT
GTRN  BCD   (SEC)    OTHER ALT    OWN ALT    OTHER  OWN      TAU0    TAU1    TAU2   TAU2P        BITS     STATUS
---- ---  --------- ----------   -------    -----  ---      ----    ----    ----   -----        -----     ------
   2 4277   352.712       7500       11300     000  000    130.729 130.729 115.762 115.762       0001         00

   3 4233   352.712      11500       11300     000  000    118.252 118.252  64.067  64.067       0010         00

TVAN    HIT 15 BCT353522723.5US CAACAACA SCP 3.958S SCN 227 PRP3999US
SLS 722/ 159. 599 NIN  95 OAL 11300FT AWN133.09 ACH 55.37 RID D
TARGETS FOR SCAN 227 RID D    TID  BCD NRP        TOA       DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---        ---       ---      --- ---- ----          ----
                                1 4277   8    9.860US   11.45     7400   97    1   11:38:46.5
                                2 2024   9   14.790US    4.00 ******  103          11:38:46.5
                                3 4277   9   14.810US   11.98     7400  107          11:38:46.6
                                4 4233   6   22.690US  -18.11    11500  104    3   11:38:46.2
ASR4    HIT 18 BCT354306275.5US ACAACAAC SCP 3.926S SCN 123 PRP2625US
SLS1091/ 261. 599 NIN 116 OAL 11300FT AWN197.11 ACH348.05 RID B
   1 4277   355.201       7500       11300     000  010    130.738 130.738 115.771 115.771       0011         00
                                            NO TURN    MAXIMUM RATE 2000 FT/MIN UP
   2 4277   355.201       7500       11300     000  010    130.729 130.729 115.762 115.762       0001         00
                                            NO TURN    MAXIMUM RATE 2000 FT/MIN UP
   3 4233   355.211      11500       11300     000  010    130.719 130.719 -33.573 -33.573       0010         21
                                            NO TURN    MAXIMUM RATE 2000 FT/MIN UP
TARGETS FOR SCAN 123 RID B    TID  BCD NRP        TOA       DAZ      TAL LTRN GTRN          TIME
                              ---  --- ---        ---       ---      --- ---- ----          ----
                                1 0200  14    2.410US   11.07 IIIIII               11:38:47.3
                                2 4277  16   46.640US   10.76     7400   91    1   11:38:47.3
                                3 4277   9   51.620US    9.73     7400  100    2   11:38:47.3
                                4 3030  13   97.200US   13.65 ******               11:38:47.4
        HIT 37 BCT356111863.6US AACAACAA SCP12.039S SCN   0 PRP2739US
        HIT 16 BCT356935229.4US AAAAAAAA SCP15.713S SCN   0 PRP3342US
        HIT 19 BCT357612860.8US ACACACAC SCP15.6716 SCN   0 PRP2505US
TVAN    HIT 13 BCT357471858.9US CAACAACA SCP 3.949S SCN 228 PRP3999US
SLS 794/ 122. 599 NIN  96 OAL 11300FT AWN133.87 ACH129.46 RID D
   1 4277   357.948       7400       11300     000  010    130.738 130.738 115.771 115.771       0011         00
                                            NO TURN    MAXIMUM RATE 2000 FT/MIN UP
```

FIGURE 5-22. BCAS QUICK LOOK RADAR/TARGET LISTING

LCAS DETAILED PROCESSING PROGRAM DATE 22 JUN 1977 PAGE 0016
RADAR/TARGET LISTING

GTRN	BCD	INTERNAL CLOCK (SEC)	OTHER ALT	OWN ALT	TIE-BREAKER D1,XC,XA OTHER	OWN	PREDICTED TIME UNTIL ALARM (SEC) TAU0	TAU1	TAU2	TAU2P	RADAR BITS	THREAT STATUS
1	4216	172.426	8800	10000	000	000	130.729	130.729	-221.025	-155.711	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	172.426	8800	10000	000	000	-20.212	-20.212	-41.717	-41.717	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	172.436	8800	10000	000	000	-18.597	-18.597	-39.883	-39.883	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	172.436	8800	10000	000	000	-13.750	-13.750	-36.082	-36.082	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
1	4216	174.717	8800	10000	000	000	130.738	130.738	-223.305	-155.702	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	174.717	8800	10000	000	000	-22.502	-22.502	-44.007	-44.007	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	174.726	8800	10000	000	000	-20.887	-20.887	-42.173	-42.173	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	174.726	8800	10000	000	000	-16.041	-16.041	-38.372	-38.372	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
5	4216	174.736	8800	10000	000	000	130.710	130.710	58.793	58.793	1000	00
							MAXIMUM RATE 2000 FT/MIN DOWN					
1	4216	177.206	8800	10000	000	000	130.738	130.738	-195.614	-155.702	1010	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
2	4216	177.216	8800	10000	000	000	-25.002	-25.002	-46.506	-46.506	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
3	4216	177.216	8800	10000	000	000	-23.377	-23.377	-44.663	-44.663	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
4	4216	177.216	8800	10000	000	000	-18.530	-18.530	-40.862	-40.862	1000	06
							MAXIMUM RATE 2000 FT/MIN DOWN					
5	4216	177.225	8800	10000	000	000	116.075	116.075	41.460	41.460	1000	00
							MAXIMUM RATE 2000 FT/MIN DOWN					

FIGURE 5-23. BCAS DETAILED PROCESSING LISTING - JUNE 1977

```
LCAS DETAILED PROCESSING PROGRAM
RADAR/TARGET LISTING                                                              DATE 6  APR 1977    PAGE    0007

TARGETS FOR SCAN  41 RID K    TID  BCD  NRP      TOA        DAZ     TAL  LTRN  GTRN            TIME
                              ---  ---  ---      ---        ---     ---  ----  ----            ----
                                1 4216   22  37.760US       .00   10600    92     5   13:13:41.4
                                2 2400    8  79.290US       .00  ******               13:13:41.4
                                3 3065   18  96.490US       .00   27800               13:13:41.4

OWN    HIT 24 BCT  3538707.3US 00000000 SCP 2.499S SCN  42 PRP3000US
SLS    0/  10- 593 NIN  24 OAL  9700FT AWN    .00 ACH218.67 RID K NPRP 1 TII  6080653.6US
```

OWN RADAR

FIGURE 5-24. BCAS DETAILED PROCESSING LISTING - APRIL 1977

```
LCAS DETAILED PROCESSING PROGRAM                                          DATE 6  APR 1977    PAGE    0006
    TOA DIFFERENTIAL AZIMUTHS                                                 FOR RADAR K SCAN    41

 .......
  7.685 ACTIVE
 .......
 14.935 ACTIVE
 .......
 17.690 ACTIVE
 .......
 22.040 ACTIVE
 .......
 26.100 ACTIVE
 26.245
 26.390 ACTIVE
 .......
 33.350 ACTIVE
 .......
 36.250 ACTIVE
 .......
 37.700 ACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVE     22
 37.845 ACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVE
 .......
 46.835 ACTIVE
 46.980 ACTIVEACTIVEACTIVE
 47.125 ACTIVE
 .......
 58.435 ACTIVE
 .......
 67.860 ACTIVEACTIVE
 .......
 79.170 ACTIVE
 79.315 ACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVE  8
 .......
 88.015 ACTIVEACTIVE
 88.160
 88.305
 88.450 ACTIVE
 88.595 ACTIVE
 88.740 ACTIVEACTIVEACTIVE
 .......
 93.815 ACTIVEACTIVE
 .......
 96.280 ACTIVE                                                                 1
 96.425 ACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVEACTIVE    11   18
 96.570 ACTIVEACTIVE                                                           2
 96.715 ACTIVEACTIVEACTIVEACTIVE                                               4
 96.860
 97.005 ACTIVE
```

FIGURE 5-25. BCAS DETAILED PROCESSING PROGRAM OF TOA AND DAZ.

```
LCAS DETAILED PROCESSING PROGRAM                                                    DATE 6  APR 1977    PAGE    0C04
TOA/DAZ REPLY LISTING FOR RADAR K SCAN   41
INTERROGATION TIME:   3470089.395      MODE: A       DAZ: ACTIVE     3000.05
 37.700  004216  79.315  002400  97.005  007421
INTERROGATION TIME    3473089.445      MODE: C       DAZ: ACTIVE     3000.05
-22.910  000000  37.845  006160  96.425  001740
INTERROGATION TIME:   3476089.495      MODE: A       DAZ: ACTIVE     3000.10
 37.700  004216  79.315  022400
INTERROGATION TIME:   3482089.595      MODE: C       DAZ: ACTIVE     6000.05
-23.055  000000  96.425  001740
INTERROGATION TIME:   3485089.645      MODE: A       DAZ: ACTIVE     3000.05
 37.700  004216  79.315  022400
INTERROGATION TIME:   3488089.695      MODE: C       DAZ: ACTIVE     3000.10
 37.845  006160  96.425  001740
INTERROGATION TIME:   3494089.795      MODE: A       DAZ: ACTIVE     6000.05
 37.700  004216  79.315  022400
INTERROGATION TIME:   3497089.845      MODE: C       DAZ: ACTIVE     3000.05
-22.910  000000  37.845  006160  96.425  001740
INTERROGATION TIME:   3500089.895      MODE: A       DAZ: ACTIVE     3000.10
 37.700  004216  46.835  012000  58.435  004000
INTERROGATION TIME:   3506089.995      MODE: C       DAZ: ACTIVE     6000.05
-23.055  000000  37.845  006160  96.425  001740                                         3546231.215
INTERROGATION TIME:   3509090.045      MODE: A       DAZ: ACTIVE     3000.15           -3518090.195
-22.910  000000  37.700  004216  79.315  022400                                           28141.020
INTERROGATION TIME:   3518090.195      MODE: C       DAZ: ACTIVE     9000.15
-22.910  000000  37.845  006160  96.425  001740
INTERROGATION TIME:   3546231.215      MODE: A       DAZ: ACTIVE
-58.145  002754  37.700  004216  88.740  000200  96.715  003044                         3549231.265
INTERROGATION TIME:   3549231.265      MODE: C       DAZ: ACTIVE                       -3546231.215
 37.845  006160  96.425  001740                                      3000.15              3000.050
INTERROGATION TIME:   3552231.315      MODE: A       DAZ: ACTIVE
 33.350  023025  36.250  011412  37.700  004216  46.980  000004  79.315  020400  88.450  005303
 96.715  003065
INTERROGATION TIME:   3558231.415      MODE: C       DAZ: ACTIVE     6000.10
 37.845  006160  96.425  001740
INTERROGATION TIME:   3561231.465      MODE: A       DAZ: ACTIVE     3000.05
 37.700  004216  46.980  000000  79.315  020400  96.715  003065     3000.05
INTERROGATION TIME:   3564231.515      MODE: C       DAZ: ACTIVE
 47.125  006160  96.425  001740                                      6000.10
INTERROGATION TIME:   3570231.615      MODE: A       DAZ: ACTIVE
-48.720  001200  37.700  004216  46.980  000000  88.595  001200  96.570  003665  3000.05
INTERROGATION TIME:   3573231.665      MODE: C       DAZ: ACTIVE
-23.055  000000  -2.465  020400   7.685  030245  14.935  003541  17.690  035620  22.040  032023
 26.390  006516  37.845  006160  67.860  000000  88.015  006112  93.815  013600  96.425  001740   3000.05
INTERROGATION TIME:   3576231.715      MODE: A       DAZ: ACTIVE                                          6000.10
 37.700  004216  79.170  002400  88.740  001000  96.570  003265
INTERROGATION TIME:   3582231.815      MODE: C       DAZ: ACTIVE
 37.845  006160  67.860  000000  88.015  006112  93.815  013600  96.280  001740
INTERROGATION TIME:   3585231.865      MODE: A       DAZ: ACTIVE
-30.160  000000  26.100  000101  37.700  004216  88.740  001200  96.715  003065
```

FIGURE 5-26. BCAS DETAILED PROCESSING PROGRAM OF TOA AND DAZ FOR K SCAN

2.5 seconds in a burst mode of 24 omnidirectional interrogations: 12 interrogations from the top antenna spaced 3 or 6 milliseconds apart, followed by a delay of approximately 18.2 milliseconds, and then 12 interrogations from the bottom antenna, again with the same repeating spacing sequence of 3 or 6 milliseconds. Meanwhile, the target aircraft (OTHER) utilized only the aircraft transponder's antenna physically located on the underside of the fuselage.

TOA and DAZ comparison plots of BCAS versus ARTS III were generated for selected test runs and are shown in Figures 5.16-34 through 5.16-51.

Threat information of each run of the climb-dive tests is summarized in Table 5-24. The following conclusions can be made on the basis of the reported data:

1. The threat code sequences are consistent with the flight patterns with only few exceptions.
2. The advisories generated in flight by the Tie-Breaker logic in the form of X, D_1 pulses (Table 5-25) and the BCAS display algorithm (Appendix C) are consistent.
3. Multiple global tracks were initiated for the target in most of the test runs. No explanation is available on the cause of these multiple tracks.

Altitude profiles of the flight trajectories derived from the BCAS and ARTS III data have been plotted for the runs numbered 1, 11, and 17, with the threat codes generated by BCAS superimposed, (Figures 5.16-52 to 5.16-54).

5.16.4 Level Flight Test Data Analysis

These tests entailed two aircraft flying daisy patterns (15° and 30° petals), one aircraft flying left turns, the other aircraft flying right turns, separated by 400' in altitude. The level flight tests were analyzed to assess the ability of BCAS to determine co-altitude threat zones. The level flight test data were processed by the same reduction programs as the data for the climb-dive tests.

TABLE 5-24. SYNOPSES OF CLIMB-DIVE TESTS

TB: Tie Breaker
DI: Display Indicator
TAU-2, 2P - always negative
TAU-0 - always positive, except in threat 30, 31, 32)

Test No.	Run Description	Threat Code Sequence	Remarks
1	Pattern A in dive, I17	07-21-31-32-20-0	3 global tracks of OTHER
2	Pattern A in climb, I17	06-16-20-21-07-20-30-07-32-31-21-00	6 global tracks of OTHER
3	Pattern A in dive, I33	00-17-21-31-32-30-20-00	ASR-4 lock was lost; regaining lock the same 2 global tracks of OTHER appeared again
4	Pattern A in climb, I33	06-30-20-00	2 global tracks of OTHER
5	Pattern A in dive, I32	07-17-31-32-30-20-00	2 global tracks of OWN; TB: Threat-fly straight and level; DI: level off no turn
6	Pattern A in climb, I32	06-00-20 - 00-30-31-21	
7	Pattern A in dive, I31	07-17-07-21-31-32-30-20-00	One global track of OTHER; TB: threat-fly straight; dive DI: level off-no turn; dive
8	Pattern A in climb, I31	32-30-31-22-00	One global track of OTHER
9	Pattern B dive-climb, I17	02-04-06-16-30-20-32-31-32-21-07	2 global tracks of OTHER; TB: threat-fly straight and level; climb; DI: level off no turn; climb no turn
10	Pattern B climb-dive, I17	00-21-31-22-32-20-30-06	3 global tracks of OTHER
11	Pattern B dive-climb, I33		No data reported.
12	Pattern B climb-dive, I33	00-05-07-17-21-32-30-06-04	No false tracks; TB: threat-fly straight and level; climb DI: level off no turn; climb no turn
13	Pattern B dive-climb, I32	31-02-30-04-20-06-32-31	Erroneous altitude codes
14	Pattern B climb-dive, I32	03-05-07-17-21-31-32-30-06-04	TB: threat-fly straight and level; dive; climb DI: no turn level off; dive; climb
15	Pattern B climb-dive, I31	16-20-30-22-32-31-21	2 global tracks: GTRN1 16-20-30-32-31-21 GTRN2 20-30-22-31
16	Pattern B climb-dive, I31	07-17-21-31-32-30-00-06-04	2 global tracks of OTHER
17	Pattern C level-dive, I33	21-31-32-30	3 global tracks of OTHER; TB: threat-dive
18	Pattern C level-climb, I17		No data reported.
19	Pattern C level-dive, I33	21-31-32-30	5 global tracks of OTHER
20	Pattern C level-climb, I33	06-30-20-30	4 global tracks of OTHER
21	Pattern C level-dive, I32	21-31-32-30-05-03	2 global tracks of OTHER
22	Pattern C level-climb, I32	20-30-32-30	

TABLE 5-25. TIE-BREAKER CODE

Bit Assignment $X_A X_C D_1$	Advisory
0 0 0	no threat
0 0 1	threat-fly straight and level
0 1 0	dive
0 1 1	climb
1 0 0	turn left
1 0 1	turn right
1 1 0	T-L and change altitude
1 1 1	T-R and change altitude

X_A bit related to the Mode-A message reply

X_C bit related to the Mode-C message reply

Hand computations were also performed to verify TAU values using BCAS measurements and threat equations in Appendix C and it was determined that the BCAS was computing the TAU values correctly - i.e., consistent with the measurements.

5.16.5 Results of BCAS TAU Analysis

Threat Logic Performance Assessment. Analysis of the data reduction output indicates that BCAS can determine the threat zones defined in Appendix C.

For both the climb-dive tests and the level flight tests, the threat status code sequences were found to be predominantly correct - i.e., consistent with the sequence of OTHER's penetration through various altitude and range boundries during the test patterns.

The BCAS computed and recorded on the detail tape a set of quantities designated as TAU-0, TAU-1, TAU-2, and TAU-2P times, which are predictions of the time until the target will enter into the corresponding threat status. These numbers were not analyzed for correctness or consistency. It was noted, however, that when

multiple global tracks were generated for a target, these quantities were different for each global track (cf. Figure 5-22). The sign of the reported values follows the following rule: when the values of TAU words are positive the aircraft is outside the corresponding regions and the specific values denote the expected time when these regions will be crossed. When the values are negative and no more negative than minus seventy-five seconds, it means the aircraft is inside that boundary.

Tie-Breaker Performance Assessment. The tie-breaker data and the dive indicator information were also analyzed. The software consistently output tie-breaker data when the system predicted a co-altitude threat (i.e., threat status codes 12, 13, 14, 15, 16, 17, 20, 21, and 22) for purposes of indicating to the ground and other BCAS equipped aircraft the anticipated evasive meaneuvers. Throughout this time period, the dive indicator would instruct the pilot to maintain level flight. When the TAU-1 boundary was penetrated, the dive indicator would immediately display the previously forecast evasive maneuver.

The tie-breaker bits should be distinguishable by other aircraft in the vicinity. However, this information was occasionally received incorrectly by the ARTS III site, in the sense that the ARTS III logic associated the tie-breaker bits with a wrong target. Thus, if this technique were being used operationally, there would be occasions when the ground controller's display would attribute planned evasive action to the wrong aircraft.

6. DATA REDUCTION PROGRAMS

6.1 BCAS DATA TAPE PROCESSING

The BCAS data reduction programs developed at TSC were designed to extract the information contained on the BCAS data collection tape. Together with data from other NAFEC measurement systems, these data were used to determine BCAS system accuracies. The information on the BCAS data collection tape is grouped into the following record types:

Type 0-1	Header
Type 0-2	Header (alphabetic info)
Type 1-1	Main Beam Interrupts (unrecognized)
Type 2-1	Recognized and locked radars
Type 2-2	Recognized and locked radars (alphabetic info)
Type 2-3	Recognized and locked radars
Type 3-1	Raw replies
Type 3-2	Raw replies (interrogation table)
Type 3-3	Raw replies (reply data)
Type 4-1	First correlated replies
Type 5-1	Second correlation
Type 6-1	Third correlation
Type 7-1	Threat Info.

A detailed description of each record type, enumerating every data element within each record, is contained in Appendix E. The processing programs that process the BCAS data collection tapes and present the information in a form suitable for reading by an analyst are discussed in the following sections.

<u>BCAS Detailed Processing Program</u>

This program generates a detailed listing in readable format for record times 0-1, 0-2, 2-1, 2-2, 2-3, 4-1, 5-1, 6-1, and 7-1. By setting program switches at the time a BCAS tape is processed, it is possible to selectively print various subsets of the

information on the tape. In addition a version of the program was developed to write an image of the paper report on magnetic tape. Such tapes serve as convenient input for programs to perform further processing of the BCAS data.

A sample output listing is shown in Figure 6-1 with details provided in Table 6-1. The data elements in each group of output lines.

6.2 RANGE-BEARING CALCULATIONS

A sequence of programs have been developed that permit BCAS tapes and ARTS tapes to be used to generate plots of slant range and bearing between the BCAS aircraft and selected targets as functions of time. The calculations are performed on the PDP-10 computer at TSC and the results are plotted on the associated Calcomp plotter. Sample plots are included in this report as Figures 5.2-10 - 5.2-19 (Appendix F).

The resulting plots show BCAS-derived and ARTS-derived range and bearing values superimposed on the same plots for comparison. If the BCAS on-board interrogator has been used, the range based on active interrogations is also plotted. The ARTS-derived values are plotted with error bars corresponding approximately to their 90% confidence intervals.

Plots can be generated for range and bearings between the BCAS aircraft and any other transponder-equipped aircraft (including targets of opportunity) or between the BCAS aircraft and the fixed transponder.

6.3 ERROR ANALYSIS PROGRAM

A typical printout generated by the Error Analysis Program is shown in Figure 6-2. The listing includes TOA and DAZ measurements made by BCAS; values for TOA and DAZ computed from EAIR measurements; and the differences in these TOA and DAZ values. Associated means, standard deviations, number of samples, sums, and sums of squares are also listed for TOA and DAZ.

```
    LCAS QUICK LOOK PROGRAM                                                          DATE 14 DEC 1976     PAGE    0373
    RADAR/TARGET LISTING

A   INT259538288.6US DATE12/09/76 EXT14: 4:42.0S VER1015 MODE3 MAXTOA100.050US WAW 35D UAL 10200FT LAL  7000FT

B   RUN 7 131

    TARGETS FOR SCAN 189 RID K    TID  BCD NRP      TOA        DAZ     TAL LTRN GTRN          TIME
                                  ---  --- ---      ---        ---     --- ---- ----          ----
                                    1 1200  12  58.870US      .00    6900                14: 4:38.8
           HIT 42 BCT260714589.5US ACAACAAA SCP14.958S SCN   0 PRP2820US

C   ASRS     HIT 18 BCT260610512.2US CAACAACA SCP 4.694S SCN  92 PRP2911US
D   SLS1225/ 322. 599 NIN 128 OAL   8600FT AWN225.40 ACH298.83 RID A
                INTERNAL                       TIE-BREAKER
                  CLOCK                         D1,XC,XA    PREDICTED TIME UNTIL ALARM (SEC)      RADAR     THREAT
G   OTRN   BCD    (SEC)    OTHER ALT    OWN ALT     OTHER  OWN        TAU0    TAU1    TAU2   TAU2P         BITS      STATUS
    ----   ---  --------  ---------    -------     -----  ---        ----    ----    ----   -----         -----     ------
       1  2753   261.248      10200       8500       000  000     128.248 128.248 113.282 113.282          1011          00

E   TARGETS FOR SCAN  92 RID A    TID  BCD NRP      TOA        DAZ     TAL LTRN GTRN          TIME
                                  ---  --- ---      ---        ---     --- ---- ----          ----
                                    1 1200  13  29.510US   -12.66    6900                14: 4:42.9

    OWN      HIT 12 BCT258804995.4US 00000000 SCP 2.499S SCN 190 PRP3000US
    SLS      0/   1. 598 NIN  12 OAL   8500FT AWN     .00 ACH298.83 RID K
    TARGETS FOR SCAN 190 RID K    TID  BCD NRP      TOA        DAZ     TAL LTRN GTRN          TIME
                                  ---  --- ---      ---        ---     --- ---- ----          ----
                                    1 1200  10  60.050US      .00    6900  125           14: 4:41.3
           HIT 13 BCT261451259.1US AACAACAA SCP 4.706S SCN   0 PRP3222US
F          HIT 26 BCT261807611.1US CACACACA SCP10.110S SCN   0 PRP2860US
           HIT 14 BCT261973021.2US ACACACAC SCP14.058S SCN   0 PRP4439US
           HIT 18 BCT262298300.9US AACAACAA SCP 3.932S SCN   0 PRP2625US

    TVAN     HIT  0 BCT262311155.5US ACAACAAC SCP 4.008S SCN 189 PRP3999US
    SLS 829/ 132. 599 NIN 100 OAL   8500FT AWN135.79 ACH298.83 RID G
       1  2753   263.747      10200       8500       000  000     125.749 125.749 110.782 110.782          1011          00

    TARGETS FOR SCAN 189 RID G    TID  BCD NRP      TOA        DAZ     TAL LTRN GTRN          TIME
                                  ---  --- ---      ---        ---     --- ---- ----          ----
                                    1 1200  12  59.770US      .88    6900  126           14: 4:44.8

    OWN      HIT 12 BCT261298192.4US 00000000 SCP 2.499S SCN 191 PRP3000US
    SLS      0/   0. 599 NIN  12 OAL   8500FT AWN     .00 ACH299.44 RID K
    TARGETS FOR SCAN 191 RID K    TID  BCD NRP      TOA        DAZ     TAL LTRN GTRN          TIME
                                  ---  --- ---      ---        ---     --- ---- ----          ----
                                    1 1200  12  61.160US      .00    6900  125           14: 4:43.8

    ASRS     HIT 18 BCT265302216.1US CAACAACA SCP 4.692S SCN  93 PRP2911US
    SLS1236/ 316. 599 NIN 128 OAL   8500FT AWN225.60 ACH299.53 RID A
```

FIGURE 6-1. BCAS DETAILED PROCESSING LISTING

TABLE 6-1. TSC-BCAS DETAILED PROCESSING PROGRAM

This program generates a detailed listing in a readable format for record types 0-1, 0-2, 2-1, 2-2, 2-3, 4-1, 5-1, 6-1, and 7-1.

Figure 6-1 is a sample annotated listing containing the following abbreviations:

A. Type 0-1 message

INT: internal clock time in μ seconds
EXT: external clock time; hours, minutes and seconds to the nearest tenth of a second.
VER: the BCAS version number
MAXTOA: maximum TOA in μ seconds
WAW: widened azimuth window in degrees
UAL: upper altitude envelope for OWN
LAL: Lower altitude envelope for OWN.

B. Type 0-2 message

Contains up to 78 alphanumeric characters entered as a title or run description.

C. Contains Type 2-1 and Type 2-2 information

ASR-5: denotes external radar identification of locked radar

HIT: number of interrogations of OWN in the main beam
BCT: internal clock time of OWN's beam center
CAACAACA: interrogation mode interlace for the last 8 interrogations
SCP: scan period of the radar in seconds
SCN: denotes the scan number of the radar from radar lock
PRP: pulse repetition periods; for an ASR-7 radar, 8 such periods are denoted.

D. Contains Type 2-2 and Type 2-3 information

SLS: # of sidelobe suppressions
322: # of missed interrogations
599: radar quality number
NIN: # of interrogations in the widened azimuth window
OAL: OWN's altitude in feet
AWN: OWN'S azimuth
ACH: aircraft heading
RIDA: internal radar identification. This is used to equate target reports to the appropriate external radar (e.g., ASR-4).

TABLE 6-1. TSC-BCAS DETAILED PROCESSING PROGRAM (Cont.)

E. Contains Types 4-1, 5-1, and 6-1 record types

SCAN: scan number
RIDA: internal radar identification
TID: target identification
BCD: beacon code
NRP: # of replies
TOA: time of arrival in μ seconds
DAZ: differential azimuth
TAL: target's altitude.

<u>Type 5-1</u>

LTRN: local track number.

<u>Type 6-1</u>

GTRN: global track number.

F. Contains Type 2 information for an unlocked radar; similar to C above.

G. Type 7-1 message.

GTRN:	global track number
BCD:	beacon code
INT:	internal clock time in seconds
OTHER'S	altitude in feet
OWN'S	altitude in feet
OTHER'S	tie-breaker bits (D_1, X_c, X_a)
OWN'S	tie-breaker bits (D_1, X_c, X_a)
TAUO	range/range rate from active
TAU1	time to penetrate 25 sec. line
TAU2	time to penetrate 40 sec. line
TAU2P	passive data - 40 sec. line.

TBA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0002
TARGET CODE: 0777 RUN 2 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TBA	EAIR TBA	TBA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:12: 4.3	5	18.510	18.146	.364	-1.791	-1.545	-.246
11:12:12.7	7	23.740	23.454	.286	-2.241	-1.689	-.552
11:12:16.6	8	26.530	26.253	.277	-2.450	-1.722	-.728
11:12:24.5	10	32.260	31.910	.350	-1.851	-1.730	-.121
11:12:28.4	11	35.110	34.897	.213	-2.076	-1.688	-.388
11:12:32.3	12	38.170	37.843	.327	-1.741	-1.703	-.038
11:12:36.2	13	41.130	40.712	.418	-2.247	-1.720	-.527
11:12:40.2	14	44.120	43.776	.344	-2.098	-1.766	-.332
11:12:48.0	16	50.250	49.894	.356	-2.263	-1.947	-.316
11:12:51.9	17	53.320	52.890	.430	-2.192	-2.074	-.118
11:12:55.8	18	56.420	56.007	.413	-2.390	-2.195	-.195
11:12:59.7	19	59.520	59.210	.310	-1.588	-2.298	.710
11:13: 3.7	20	62.660	62.305	.355	-2.653	-2.382	-.271
11:13: 7.6	21	65.760	65.328	.432	-2.131	-2.434	.303
11:13:11.5	22	68.920	68.515	.405	-3.071	-2.463	-.608
11:13:15.4	23	72.010	71.646	.364	-2.889	-2.514	-.375
11:13:19.4	24	75.180	74.702	.478	-2.494	-2.630	.136
11:13:23.3	25	78.190	77.710	.480	-3.005	-2.839	-.166
11:13:27.2	26	81.340	80.868	.472	-2.653	-3.095	.442
11:13:31.2	27	84.410	84.078	.332	-3.505	-3.343	-.162
11:13:39.0	29	90.620	90.073	.547	-3.895	-3.715	-.180
11:13:42.9	30	93.740	93.202	.538	-3.933	-3.885	-.048
11:13:46.9	31	96.740	96.376	.364	-3.867	-4.108	.241

DAZ MEAN:	-.154	DAZ S.D.:	.344	N= 23	SUM=	-3.539	SUM OF SQUARES= 3.142
TBA MEAN:	.385	TBA S.D.:	.083	N= 23	SUM=	8.855	SUM OF SQUARES= 3.559

FIGURE 6-2. ERROR ANALYSIS

In addition the Error Analysis Program processes BCAS versus ARTS III data.

6.4 PLOTTING PROGRAM

Computer generated plots of TOA, DAZ and OWN AZ depicting BCAS measurements and either EAIR measurement or ARTS III measurements are generated by this plot program. Examples of these plots are shown in Figures 5.2-1 - 5.2-9 (Appendix F).

6.5 TOA/DAZ REPLY LISTINGS

Figure 6-3 shows a typical printout of the TOA/DAZ Reply listing. The listing indicates the interrogation time, the interrogation mode, the DAZ and, for the reply(s) received, the TOA and the reply in octal format.

6.6 TOA/DAZ HISTOGRAM TABLE

The Histogram Table Program duplicates the manner in which reply data are processed by the software on board the BCAS system for purposes of target report declaration.

The Histogram Table (see Figure 6-4) lists TOA bins from 0.000 μ seconds to 150 μ seconds with the reply entries depicted in histogram format within the appropriate TOA bin by their associated DAZ value.

6.7 FRUIT SUSCEPTIBILITY PROGRAM

This program processes reply data received by BCAS and calculates over a prescribed time interval, on a per scan basis, the number of transponder replies, the number of fruit replies, percentage of fruit, means, and standard deviations (see Table 5-9).

6.8 ARTS III PROCESSING

The data reduction programs developed at TSC were designed to utilize the information contained on the ARTS III data extraction tapes as a means of monitoring BCAS system testing and to generate

SUB-SYSTEM 1 ASSIGNED BEACON CODE 4572 TAPE ID: 9048 FILE 1 SEGMENT 1 PAGE 29

SCAN	TIME	ACID	RBC	C	ALT	RANGE	AZIMUTH	VELOCITY	DIRECTION	FIRM	W/S	VA	VC	RUN	HIT
1	4:10:44	N49	4572	1	100	11.50	214.80	190.27	332.49	37					
1	4:10:44				100	11.50	215.33				0	3	2	12	11
2	4:10:48	N49	4572	1	100	11.37	215.86	195.01	332.05	37					
2	4:10:48				0	11.44	216.56				0	3	0	8	7
3	4:10:52	N49	4572	1		11.31	217.00	201.47	330.75	37					
3	4:10:51				100	11.31	216.47				0	3	2	13	10
4	4:10:56	N49	4572	1	100	11.19	217.79	195.01	332.05	37					
4	4:10:55				100	11.25	217.79				1	3	3	19	16
4	4:10:55				100	11.25	211.99				0	3	2	17	9
5	4:11: 0	N49	4572	1	100	11.12	218.76	195.01	332.05	37					
5	4:10:59				100	11.19	219.02				1	3	2	19	15
6	4:11: 4	N49	4572	1	100	11.06	219.81	196.69	331.14	37					
6	4:11: 3				100	11.12	220.08				1	3	3	17	15
7	4:11: 8	N49	4572	1	100	11.00	220.96	196.69	331.14	37					
7	4:11: 7				100	11.00	221.04				0	3	3	15	11
8	4:11:11	N49	4572	1	100	10.94	222.01	196.69	331.14	37					
8	4:11:11				100	10.94	222.10				1	3	3	18	16
9	4:11:15	N49	4572	1	100	10.87	223.07	196.69	331.14	37					
9	4:11:15				140	10.87	222.98				0	3	2	20	12
10	4:11:19	N49	4572	1	140	10.75	224.12	196.69	331.14	37					
10	4:11:19				100	10.81	223.77				1	3	3	20	16
11	4:11:23	N49	4572	1	100	10.69	225.09	191.92	331.56	37					
11	4:11:23				100	10.75	225.35				1	3	2	19	15
12	4:11:27	N49	4572	1	100	10.69	226.23	191.92	331.56	37					
12	4:11:27				100	10.69	226.05				0	3	3	18	10
13	4:11:31	N49	4572	1	100	10.62	227.29	191.92	331.56	37					
13	4:11:31				100	10.62	227.55				1	3	3	17	14
14	4:11:35	N49	4572	1	100	10.56	228.43	191.92	331.56	37					
14	4:11:35				121	10.62	228.43				1	3	2	22	19
15	4:11:39	N49	4572	1	121	10.50	229.57	191.92	331.56	37					
15	4:11:39				100	10.56	229.92				1	3	3	18	14

FIGURE 6-3. FLIGHT HISTORY

SUB-SYSTEM 1 ASSIGNED BEACON CODE 4572 TAPE ID: 9048 FILE 1 SEGMENT 1 PAGE 41

SCAN	TIME	ACID	RBC	C	ALT	RANGE	AZIMUTH	VELOCITY	DIRECTION	FIRM	W/S	VA	VC	RUN	HIT
181	4:22:30	N49	4572	1	103	12.50	274.48	229.81	150.69	37					
181	4:22:30				99	12.56	274.39				1	3	2	16	13
182	4:22:34	N49	4572	1	099	12.37	273.43	231.20	151.88	37					
182	4:22:34				3	12.37	273.34				1	3	2	20	18
183	4:22:38	N49	4572	1	103	12.25	272.37	235.97	151.53	37					
183	4:22:38				99	12.25	272.29				1	3	2	20	17
184	4:22:42	N49	4572	1	099	12.12	271.32	235.97	151.53	37					
184	4:22:42				0	12.12	270.97				0	3	0	29	22
185	4:22:46	N49	4572	1		12.00	270.09	239.06	151.93	37					
185	4:22:46				100	12.00	270.53				1	3	2	21	18
186	4:22:50	N49	4572	1	100	11.87	269.21	235.97	151.53	37					
186	4:22:50				150	11.87	270.00				1	3	2	16	16
187	4:22:54	N49	4572	1	150	11.75	268.42	229.81	150.69	37					
187	4:22:54				141	11.75	268.33				1	3	2	19	15

FLIGHT SUMMARY

TARGET STATISTICS:

NUMBER OF TARGET REPORTS FOR THIS FLIGHT IS 182
NUMBER OF FALSE TARGETS IS 10
PROBABILITY OF FALSE TARGET PER SCAN IS .055
AVERAGE RUN LENGTH PER SCAN IS 19.5
AVERAGE HIT LENGTH PER SCAN IS 15.0
ROUND RELIABILITY IS 76.6 PERCENT
TARGET DETECTION PROBABILITY PER SCAN IS .973
PROBABILITY OF STRONG TARGET PER SCAN IS .637
DISTRIBUTION OF VALIDITY INDICATORS (PERCENT)

	0	1	2	3
VA	.0	.5	.0	99.5
VC	6.0	11.0	44.5	38.5

TRACKING STATISTICS:

BLIP-SCAN WITH TAB CROST IS .984
BLIP-SCAN WITHOUT TAB CROST IS .984

6-4. FLIGHT HISTORY II

measures of BCAS interference (North/South Pulse Kit and Active Modes) on the ATCRBS beacon environment. Information contained on the data extraction tapes includes:

DAS Replies - contain the beacon code or altitude, range, emergency and radio failure indicators, and a garble indicator.

Target Reports - contain range, altitude, beacon code, azimuth and VA and VC validity indicators.

Track Messages - contain the highest order of data output and provide an indication of what the controller sees on his DEDS console.

Sector Times - contain the time a sector boundary is crossed (every 11.5°; i.e., 32 times per scan). The time recorded is the ARTS III System Time which is generally the current Greenwich Mean Time.

For the NAFEC ARTS III system, a modification was made to the software to extract additional ARTS III data base information. This data included ARTS III generated target run length and number of hits on a per target basis. This is important information, since it provides the analyst with the actual number of replies correlated each scan for each target and the total number of interrogations between the first and last reply correlated for each target on each scan (run length).

A brief description of the major data reduction programs follows.

6.9 FLIGHT HISTORY PROGRAM

As the name of the program indicates, a flight history listing outputs pertinent information for the particular segment of interest (i.e., from $t_i - t_f$), with the entries in numerical ascending sequence of scan numbers for the specific aircraft, and the aircraft ordered by beacon code.

Figure 6-3 shows a segment of a typical flight history for aircraft N49 reporting on beacon code 4572. The first data time is the ARTS III track report for the specified scan; it is followed by the corresponding target report generated for the same scan. Note that in scan 4, an additional target report was generated due to target splitting. It is evident from examination of range and azimuth data which of the target reports is true and which is false.

Figure 6-4 shows a continuation of the same flight segment for aircraft N49 and contains performance measurements statistics for the flight segments as follows:

NT	number of target reports
NF	number of false targets
PF	probability of false target per scan
RL	run length
NH	number of hits
RR	round reliability
PD	probability of detection
PS	probability of strong target.

Of the eight performance measurements, the most important ones are run length, number of hits, and round reliability. Round reliability is defined as the probability that the transponder will reply to a detected interrogation and that the resulting reply will be detected by ATCRBS. Lowered round reliability affects the ATCRBS system in three ways: First, it reduces the number of hits in the reply sequence, thereby creating holes in the sequence and hindering target detection and code validation. Second, it can produce a random distribution of misses which may alter the apparent target centroid, thereby limiting azimuth accuracy. Third, it can cause azimuth splitting (i.e., multiple declarations of the same target).

6.10 CHRONOLOGICAL SCAN PROGRAM

The chronological scan listing (see Figure 6-5) contains the same pertinent information as the flight history listing;

SUB-SYSTEM 1 SCAN 1 TAPE ID: 6232 FILE 3 SEGMENT 1 PAGE 2

ABC	TIME	ACID	FLG	C	ALT	RANGE	AZIMUTH	SPR	LPR	SPA	LPA	W/S	VA	VC	RUN	HIT
0530	3: 0:20		1		0	37.19	309.55					1	3	0	17	15
1276	3: 0:17	TSC1276		1		1.31	37.18	.87	1.69	20.30	54.05					
1276	3: 0:16		1		0	1.31	38.23					1	3	0	21	17
1603	3: 0:19		0		97	19.19	255.76					1	3	3	22	20
2552	3: 0:17		0		114	30.56	56.07					1	3	3	23	20
2634	3: 0:16		0		116	58.94	28.39					0	3	3	18	13
2640	3: 0:18		0		350	24.69	135.35					1	3	3	24	21
2640	3: 0:18		0		350	24.75	181.93					1	3	3	25	22
2677	3: 0:18		0		382	30.44	193.62					1	3	3	19	16
2767	3: 0:20		0		235	51.87	354.02					1	3	3	18	16
3216	3: 0:20		0		163	20.44	341.89					1	3	3	19	15
3224	3: 0:16		0		162	41.12	35.24					1	3	3	20	19
3343	3: 0:20		0		51	42.00	296.28					0	3	3	13	13
3346	3: 0:18	TSC3346		1		35.94	174.99	35.56	36.25	173.85	176.04					
3346	3: 0:18		1		0	36.06	176.22					0	3	0	7	5
3354	3: 0:19		0		96	48.37	274.22					1	3	3	20	19
3374	3: 0:20		0		190	4.37	289.42					0	3	2	14	13
3543	3: 0:16		0		83	22.56	18.02					1	3	3	20	19
4120	3: 0:16		1		0	1.12	25.40					0	3	0	15	10
4321	3: 0:16		1		0	1.12	21.71					1	3	0	27	19
4777	3: 0:19		0		19	38.81	236.60					0	3	3	13	12

FIGURE 6-5. CHRONOLOGICAL SCAN

however the data is output by scan number, with the aircraft entries ordered by beacon code. Again, the same eight performance measurements are indicated and the associated statistics relate to the specified scan.

6.11 REPLY/TARGET REPORT

A typical printout for the reply/target report listing is shown in Figure 6-6. This listing indicates the mode and azimuth of each interrogation and the altitude, transponder code, and range of all replies received from that interrogation. Since it is not necessary to print out interrogations that do not result in reception of replies, a column has been added on the far right indicating the number of sequential interrogations with no replies. This information tells the analyst the number of interrogations that have elapsed since the last received reply without actually printing out these interrogations. Target report messages are interspersed in the listing and contain run length, number of hits, and the sequential interrogation pattern of replies correlated to the target report. The target report messages are identified numerically and their correlated replies have the same numerical identification; where appropriate, reply data is indicated fruit (F) and garble (G).

6.12 FLIGHT STATISTICS

The Flight Statistics Program calculates quantitative measures of BCAS interference on the ATCRBS beacon environment. During interference testing of the North/South Pulse Kit, of High Rate of Active Interrogation and of Manual Mode of Active Interrogation, the system under test undergoes short periods of time (30 seconds to a minute) of alternate "ON" and "OFF" cycles. Information is collected on the ARTS III data extraction tapes and is subsequently processed by this program for consecutive ON/OFF cycles. Figures 6-7 through 6-9 show typical output listings. Figures 6-7 and 6-8 contain the eight performance measures of the

GMT HR:MIN:SEC ID BEACON CODE	MESSAGE TYPE ALT. 100'S FEET	MODE A/C RANGE N. MILES	AZIMUTH (DEGREES) AZIMUTH DEGREES	ALTITUDE (FEET) TIME OF TARGET	TRANSPONDER CODE	RANGE (N.M.) CODES VA VC	SEQUENTIAL HITS	INTERROGATIONS WITH NO REPLY LENGTH PATTERN	GARBLE INDICATOR	FOR TARGET REPORTS
	INTERR.	A	336.27					0		
31	REPLY				2662	38.25				
	INTERR.	C	336.53					0		
31	REPLY			2200		38.25				4005401144 0004357241
	INTERR.	A	336.80					0		
31	REPLY				2662	38.25				
	INTERR.	A	336.97					0		
31	REPLY				2662	38.25				
	INTERR.	C	337.24					0		
31	REPLY			2200		38.25				4005401144 0004357641
15:36:42.84 31 2662	25	38.25	335.92	15:36:42.84		3 3	12	139999 14 ACAA.AA.AACAAC.		
	INTERR.	A	341.81							
F	REPLY				1200	26.56				
32	REPLY				1200	30.75				
	INTERR.	A	342.33					1		
F	REPLY				1200	26.50				
32	REPLY				1200	30.69				
	INTERR.	A	342.51					0		
32	REPLY				1200	30.69				
	INTERR.	A	342.95					1		
32	REPLY				1200	30.69				
	INTERR.	A	343.21					0		
32	REPLY				1200	30.69				
	INTERR.	C	343.48					0		
-33	REPLY			3800		27.94				4014100677 0004364201
	INTERR.	A	343.65					0		
32	REPLY				1200	30.75				
	INTERR.	A	343.92					0		
32	REPLY				1200	30.75				
	INTERR.	C	344.18					0		
G	REPLY			1800		26.50			GARBLED	7007400650 0004364601
G	REPLY			27200		27.94			GARBLED	6054100677 7007400650
	INTERR.	A	344.36					0		
33	REPLY				1700	27.87				
32	REPLY				1200	30.69				
	INTERR.	A	344.62					0		
33	REPLY				1700	27.94				
32	REPLY				1200	30.75				
	INTERR.	C	344.88					0		
G	REPLY			1200		26.50			GARBLED	7006400650 0004365201
G	REPLY			27200		27.94			GARBLED	6054100677 7006400650
	INTERR.	A	345.06					0		
F	REPLY				1200	26.56				
33	REPLY				1700	27.87				

FIGURE 6-6. REPLY/TARGET REPORT

SUBSYSTEM 1 SEGMENT 1

CODE	NT	NF	PF	RL	NH	RR	PD	PS
0303	24	0	.000	24.250	16.458	67.869	.960	.458
0503	25	0	.000	27.560	24.400	88.534	1.000	.880
0506	25	0	.000	25.040	23.360	93.291	1.000	1.000
0520	25	0	.000	20.120	18.160	90.258	1.000	.680
0560	24	0	.000	22.208	21.208	95.497	.960	.958
1607	24	0	.000	24.292	20.333	83.705	.960	.833
1611	24	0	.000	22.583	19.458	86.162	.960	.708
1612	24	0	.000	26.333	21.000	79.747	1.000	.875
1625	25	0	.000	24.240	21.120	87.129	1.000	.960
1641	22	0	.000	22.636	19.409	85.743	.917	.773
1643	25	0	.000	27.440	23.680	86.297	1.000	.920
1706	24	0	.000	21.792	18.542	85.086	.960	.792
1743	6	1	.167	16.333	11.833	72.449	1.000	.167
3015	18	1	.056	36.111	25.444	70.462	.720	.167
3057	25	0	.000	23.320	18.560	79.588	1.000	.680
3366	25	5	.200	29.920	22.280	74.465	1.000	.720
3377	24	0	.000	22.458	19.792	88.126	.960	.875
3404	20	0	.000	17.500	15.500	88.571	.800	.400
3464	24	0	.000	17.000	15.958	93.873	1.000	.542
3535	6	1	.167	31.500	17.000	53.968	.273	.667
3540	24	0	.000	31.292	25.875	82.690	.960	.667
3541	24	0	.000	25.250	21.125	83.663	.960	.958
4150	24	1	.042	29.250	23.042	78.775	.960	.792
4266	24	6	.250	32.042	25.833	80.624	.960	.500
4325	25	1	.040	29.280	22.360	76.366	1.000	.760
4354	25	1	.040	30.320	24.960	82.322	1.000	.600
4520	21	0	.000	22.571	20.714	91.772	.955	.857
4521	25	1	.040	25.800	22.000	85.271	1.000	.800
5101	25	0	.000	21.280	19.600	92.105	1.000	.920
5110	15	0	.000	21.200	18.200	85.849	1.000	.667
5336	24	0	.000	20.958	20.125	96.024	.960	.875
5340	25	1	.040	23.880	20.960	87.772	1.000	.880
5513	24	0	.000	20.500	19.333	94.309	1.000	.792
6206	22	0	.000	31.273	24.864	79.506	.917	.364
7202	24	0	.000	31.417	21.833	69.496	.960	.542
7532	22	0	.000	23.818	17.682	74.237	.880	.545
7537	22	0	.000	21.727	16.909	77.824	.880	.636

6-7. FLIGHT STATISTICS I

SUBSYSTEM 1 SEGMENT 2

CODE	NT	NF	PF	RL	NH	RH	PD	PS
0303	24	0	.000	29.667	18.417	62.079	.923	.333
0503	25	0	.000	31.120	26.800	86.118	1.000	.840
0506	24	0	.000	26.292	24.167	91.918	.960	.958
0520	25	0	.000	21.400	19.800	92.523	1.000	.800
0560	25	0	.000	28.720	26.600	92.618	1.000	.760
1607	25	0	.000	23.160	18.920	81.693	1.000	.760
1611	25	0	.000	21.840	17.880	81.868	.962	.600
1612	26	0	.000	25.885	22.538	87.073	1.000	1.000
1625	25	0	.000	25.360	21.760	85.804	1.000	.880
1641	26	0	.000	22.846	19.923	87.205	1.000	.962
1643	24	0	.000	25.708	23.000	89.465	1.000	1.000
1706	26	20	.769	22.192	17.962	80.936	1.000	.731
1743	24	0	.000	25.542	20.167	78.956	.960	.708
3015	21	6	.286	37.095	25.095	67.651	.808	.000
3057	23	0	.000	25.435	21.043	82.735	.920	.870
3366	26	0	.000	28.000	22.808	81.456	1.000	.923
3377	25	0	.000	24.040	22.400	93.178	1.000	.960
3404	15	0	.000	16.333	14.000	85.714	.600	.267
3464	25	0	.000	19.400	17.320	89.278	.962	.720
3535	6	0	.000	33.500	15.667	46.766	.273	.500
3540	24	0	.000	26.583	24.292	91.379	.960	.917
3541	25	0	.000	29.400	22.280	75.782	.962	.840
4150	25	0	.000	35.080	27.920	79.590	1.000	.320
4266	13	0	.000	25.769	20.846	80.896	.650	.692
4325	25	1	.040	25.400	22.200	87.402	1.000	.840
4354	24	0	.000	29.500	23.417	79.379	.960	.792
4520	25	0	.000	25.560	24.080	94.210	1.000	1.000
4521	23	0	.000	25.652	22.000	85.763	.920	.870
5101	26	2	.077	23.115	20.192	87.354	1.000	.846
5110	22	0	.000	18.500	16.818	90.909	.846	.545
5336	25	0	.000	24.600	22.640	92.033	1.000	1.000
5340	26	0	.000	24.154	21.577	89.331	1.000	.923
5513	20	1	.050	18.450	16.550	89.702	.909	.650
6206	26	0	.000	30.769	27.000	87.750	1.000	.731
7202	24	0	.000	30.458	21.833	71.683	.923	.625
7532	23	0	.000	25.652	21.261	82.881	.885	.826
7537	23	0	.000	23.826	18.000	75.547	.920	.783

FIGURE 6-8. FLIGHT STATISTICS II

indicated aircraft for the ON and OFF cycle respectively. Figure 6-9 denotes the mean and standard deviation of the eight performance measurements for the contiguous ON and OFF cycles.

6.13 WIDENED AZIMUTH WINDOW

The Widened Azimuth Window Program processes target report messages of aircraft that are present in the widened azimuth window of BCAS. In processing these aircraft (beacon codes), range, azimuth and altitude data are listed (see Figure 6-10) with respect to OWN and generates corresponding TOA's, DAZ's, Ranges and Bearings.

6.14 X&D_1 PULSE ANALYSIS PROGRAM

This program analyzes the current erroneous use of the X and D_1 pulses in the transponder reply train as a means of assisting the analyst in determining the viability of the use of these pulses to indicate the direction of potential maneuvers of BCAS equipped aircraft.

SUBSYSTEM 1

	ON		OFF	
	SEGMENT 1		SEGMENT 2	
QUANTITY	MEAN	DEVIATION	MEAN	DEVIATION
NT	22.541	4.531	23.351	4.029
NF	.514	1.283	.811	3.406
PF	.028	.062	.033	.134
RL	24.986	4.664	25.838	4.485
NH	20.511	3.192	21.329	3.288
RR	82.957	8.923	83.422	9.532
PD	.942	.128	.927	.143
PS	.708	.210	.751	.228

FIGURE 6-9. FLIGHT STATISTICS III

AD-A058 936 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 1/4

EXPERIMENTAL BCAS PERFORMANCE RESULTS.(U)

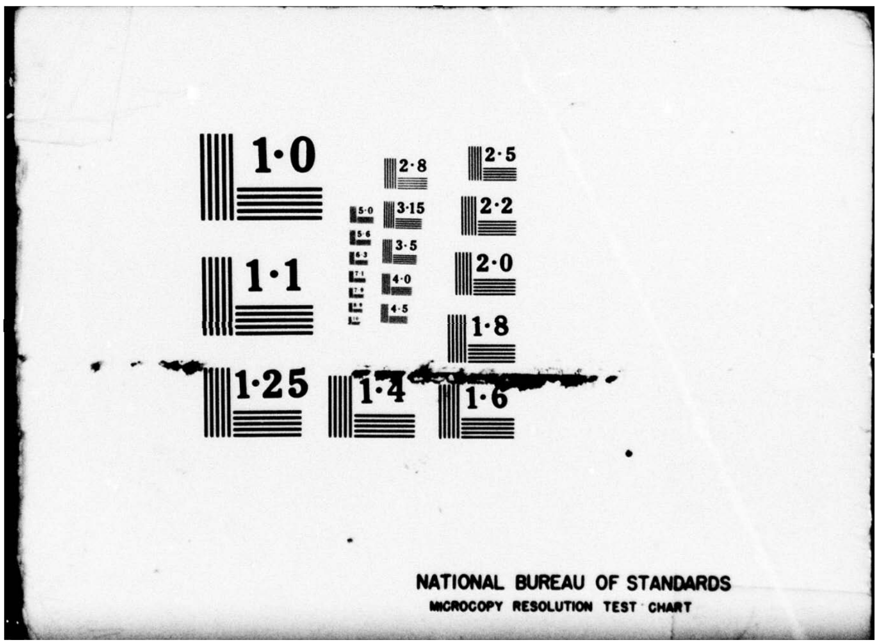
JUL 78 J VILCANS, E QUISH, J G RAUDSEPS

UNCLASSIFIED TSC-FAA-78-9 FAA-RD-78-53 NL

3 OF 5

ADA

058936


1.0
2.8
2.5
5.0
3.15
2.2
5.6
3.5
6.3
2.0
1.1
4.0
4.5
1.8
1.25
1.4
1.6
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

SUBSYSTEM 1 SCAN 36 BXN CODE 0311

CODE	TIME	RANGE	AZIMUTH	ALTITUDE	TOA	DAZ	RANGE	BEARING	RUN	HIT
0777	12: 8:21.367	12.1875	287.930	2(.0329)	62.671	-10.547	5.4575	273.007	14	10 A.CAAC.A.A.CAA
2363	12: 8:21.492	55.6875	292.148	238(3.9170)	596.383	-6.328	48.3521	291.194	12	8 CA..A..AA.AAC.AC
0311	12: 8:21.492	7.5000	298.477	105(1.7281)	.000	.000	.0000	UNDEFINED	17	9 A.CA...A.A.C.A.AA
1757	12: 8:21.633	18.0625	304.805	304(5.0032)	131.043	6.328	10.6501	309.358	21	11 ACA..A.C...A.C.A.A.CA
2772	12: 8:21.633	28.6250	308.496	81(1.3331)	263.001	10.020	21.4483	311.891	14	11 A...C.ACAACAACA..A

FIGURE 6-10. WIDENED AZIMUTH WINDOW

7. NAFEC PROGRAMS

7.1 NAFEC-BCAS PROGRAM

The following data reduction and conversion programs were used at NAFEC and provided the described outputs:

1. EAIR program - provided unsmoothed positional coordinates X, Y, Z, in one-tenth second increments, in binary or binary coded decimal format. Data was usually rotated and translated to the reference coordinates of the ASR-5. Tapes and hardcopy printouts were provided to TSC.

2. NAFEC Geodetic Position Coordinate Program - provided coordinates for the Mizpah reference transponder relative to the ASR-4 and ASR-5.

3. BCAS Data Reduction Program - converted the octal format of the BCAS data tape to a specified hard copy printout format.

4. BCAS-ARTS III Data Reduction Program - provided beacon-only target report data and derived values of TOA and DAZ. This program was used with the standard ARTS III dual beacon data extractor and the TSC modified version (A09).

5. BCAS-ARTS III Error Program - this program is an error prediction model of ARTS III for inputs of aircraft geometrics (2) and error statistics (slant range, azimuth, and altitude). Predicted error statistics of ARTS III derived range separation, time of arrival, and differential azimuth were obtained. Two versions of the program were written; one to be used on the NAFEC 9020 computer and another provided to TSC together with a typical case printout.

7.2 NAFEC DATA ANALYSIS

During the test program a number of different statistics were computed. The major analyses made at NAFEC were:

1. Comparison of range and azimuth reported by ARTS III with EAIR data.
2. Comparison of TOA and DAZ as measured by the BCAS equipped aircraft, in flights past the fixed transponder at Mizpah, with EAIR derived TOA and DAZ.
3. Comparison of TOA and DAZ as measured by BCAS with ARTS III derived TOA and DAZ.
4. Comparison of ARTS III, EAIR and Phototheodolite data for the following purposes:
   a. to qualify the ARTS III target report data in terms of mean and standard deviation estimates for errors in range, azimuth and differential azimuth
   b. to investigate the correlation between different sets of ARTS III azimuth data.

APPENDIX A: POTENTIAL IMPACT ON BCAS PERFORMANCE DUE TO ATCRBS IMPROVEMENTS/MODIFICATIONS

1. INTRODUCTION

A number of improvements and modifications are being implemented or planned in the ATCRBS system to overcome or mitigate present system problems. In this Appendix, a selection process is carried out to determine which improvements have a potential impact on BCAS operation and the related actions required. In FAA ORDER 6360 "Air Traffic Control Radar Beacon System (ATCRBS) Improvement Program", the problems in the present ATCRBS system are identified and described. To solve these problems, a number of solutions, improvements and modifications are proposed, as described in the above cited ORDER. In Table I are listed the identified problems and in Table II are given, in matrix form, the proposed solutions versus the problems to be solved. These various categories of improvements/modifications are examined to determine which ones have a potential impact on BCAS and deserve further studies and analysis.

2. CATEGORIES OF ATCRB IMPROVEMENTS/MODIFICATIONS

As shown in Table II, ATCRBS improvements are divided in three general categories:

CATEGORY A: - Alignment, Maintenance, Evaluation of Present System.

CATEGORY B: - Optimization of Present System Environment.

CATEGORY C: - Upgrade System Hardware/Software.

Fourteen (14) proposed improvements/modifications are listed under these categories. In FAA ORDER 6360 a number of actions are recommended under each of these 14 items. Only the relevant improvements/modifications to the problem at hand were abstracted for assessing their potential impact on BCAS performance. In Table III these selected items are listed alongside with the identified potential impact on BCAS and the actions to be taken. Four (4) items appear to have a potential impact on BCAS operation:

TABLE I. DESCRIPTION OF ATCRBS PROBLEMS

a. False targets caused by reflections

b. False targets caused by sidelobes

c. Erroneous or missing Mode C replies

d. Double targets

e. Azimuth splits

f. Loss of targets caused by holes in coverage pattern

g. Range splits

h. Loss of targets caused by reduced low-angle coverage

i. Phantom target reports and garbled code data

j. False targets caused by synchronous fruit and second-time-around replies

TABLE II. CROSS-REFERENCE: PROBLEMS VS. SOLUTIONS

PROBLEMS \ SOLUTIONS	A1. Test Equipment	A2. System Performance	A3. Power Reduction	A4. Transponder Improvements	A5. Site Standardization	A6. Site Technical Inspection	B1. Parameter Optimization	B2. Improve Site Environment	B3. Discrete Code Allocation	C1. Improved Antenna	C2. CD Modification	C3. ARTS Modification	C4. Software Enhancement	C5. Interrogator Modification
1. False Targets caused by Reflections	X	X	X	X		X	X	X	X	X			X	X
2. False Targets caused by Sidelobes	X	X	X	X		X		X	X	X			X	X
3. Erroneous/Missing Mode C Replies	X	X		X		X	X			X	X	X	X	X
4. Double Targets	X	X		X	X	X				X		X	X	X
5. Azimuth Splits				X			X	X	X					
6. Range Splits					X		X		X		X			
7. Loss of Targets	X	X	X	X	X	X	X	X		X	X	X	X	X
8. Phantom Targets. Garbled Codes				X							X			
9. False Targets caused by Synchronous Fruit			X			X								X

TABLE III. ATCRBS IMPROVEMENTS AND POTENTIAL IMPACT ON BCAS

Category A. (Alignment Maintenance, Evaluation)	Relevant ATCRBS Improvements/Modifications	Potential Impact on BCAS	Action Required
A.1. Test Equipment			
1) Provide Properly Calibrated Test Equip. for Site Evaluation and Maintenance	• Upgrades Hardware Performance	• Beneficial	• None
A.2. System Performance/Certification Parameters			
1) Upgrade Maintenance and Certification Proceedures	• Upgrades System Performance	• Beneficial	• None
A.3. Power Reduction			
1) Reduce Power to Minimum Requirements. Adjust DIREC/OMNI. Power Ratio	• Reduces Interference • Improves Side Lobe Suppression	• Reduce Coverage Area. • Reduces Range of SLS Signal.	• Assess Impact on Coverage
A.4. Transponder Improvement			
1) Assure Proper Operation of Transponders.	• Tighten Federal Standards • Upgrade Testing	• Beneficial	• None
A.5 Site Standarization			
1) Improve Cabling, Equipment Interfaces	• Improves Grounding, Hardware Performance.	• Minimal	• None
A.6. Site Technical Inspection			
1) Provide Site Evaluation Routine	• Upgrades Maintenance, Performance	• Beneficial	• None

TABLE III. ATCRBS IMPROVEMENTS AND POTENTIAL IMPACT ON BCAS (Cont.)

Category B. Optimization of System/Enviroment	Relevant ATCRB Improvements/Modifications	Potential Impact on BCAS	Action Required
B.1. Parameter Optimization			
1) Optimize Interrogator PRF, Scan Rate, Mode Interlace, Detection Algorithm	• Improve Target Detection Validation	• None-(Unless Such Parameters are Used a Priori)	• None
B.2. Improved Site Environment			
1) Reduce/Eliminate Effect of Obstructions, Reflections.	• Remove Site Obstruction • Shield Surfaces • Relocate Radar Site if Necessary	• None-(Unless Radar Location is Used a Priori)	• None
B.3. Discrete Code Allocation			
1) Eliminate Duplication in Code Assignment	• Allocate Codes To Avoid Duplication • Allocate Code 1220 for Permanent ECND	• Beneficial	• None

TABLE III. ATCRBS IMPROVEMENTS AND POTENTIAL IMPACT ON BCAS (Cont.)

Category C. Upgrade System Hardware/Software	Relevant ATCRBS Improvements/Modifications	Potential Impact on BCAS	Action Required
C.1. Improved Antenna			
1) Develop an Improved Antenna System	a) Minimizes Vertical Lobing b) Incorporates Rotary Joint for Either "Integral" SLS or Monopulse Operation	a) Beneficial b) Unknown	a) None b) Assessment and Analysis
C.2. CD Modifications	• Beacon Reply Group Hardware Modifications	• None	• None
C.3. ARTS Modifications	• Improve Target Detection and Code Processing	• None	• None
C.4. Software Enhancement	• Improve Target Validation and Monitoring	• None	• None
C.5 Interrogator Modifications			
1) Modify Interrogator; Improve Monitoring	a) Provide Stagger/Destagger Capability to all ATCBI-3. Stagger the Mode Interrogation Signals by at Leas 25 usec.	a) Improves Radar Selection/Discrimination	None (Unless PRF, Information is used a Priori)
	b) Azimuth Gate the Power Output or STC Curve To Reduce Site Specific Reflections and Synchronous Interference From Adjacent Overlapping ATCRBS	b1. None For STC Gating b2. If Power Gated no Radar Signals Available At Some Azimuth.	b1. None b2. Site Specific Study and Analysis

TABLE III. ATCRBS IMPROVEMENTS AND POTENTIAL IMPACT ON BCAS (Cont.)

Category C. -CONTINUED	Relevant ATCRBS Improvements/Modifications	Potential Impact On BCAS	Action Required
	c) Install False Target Suppression Transmitter (Trevose Fix) for ATCRBS Sites with well Defined Reflection Problem. System Consists of a Directional Horn and an SLS/ISLS Transmitter Used to Suppress Aircraft Transponders in Area of Reflection and False Target Generation	c) Unknown-May Generate Blind Spot	c. Site Specific Study and Analysis.

A.3. POWER REDUCTION

B.2. IMPROVED SITE ENVIRONMENT

C.1. IMPROVED ANTENNA

C.5. INTERROGATOR MODIFICATIONS.

These four "filtered" items are summarized in Table IV for further assessment and analysis.

The actions required can be divided into three areas. a) updating BCAS files b) coverage studies c) ATCRBS signal structure.

a) UPDATING BCAS FILE (NO ACTION REQUIRED)

B.1 PARAMETER OPTIMIZATION
B.2 IMPROVE SITE ENVIRONMENT
C.5 INTERROGATOR MODIFICATIONS(a)

Category B.1 involves optimization of PRF, scan rate and mode interlace; category B.2 relocation of radar site; category C.5. a, installation of PRF stagger/destagger capability. At the present time, BCAS operation is independent of such improvements/modifications. However, utilization of such information a priori would require merely updating of BCAS file.

b) COVERAGE STUDIES

A.3 POWER REDUCTION (a), (b)
C.5 INTERROGATOR MODIFICATIONS (b2), (c)

In category A.3, power levels will be reduced to minimum requirements to reduce interference. This will also reduce coverage area. Therefore, BCAS coverage calculations should be based on these eventual minimum range requirements. In category C.5. b2, gating power at a specific azimuth will affect the corresponding coverage area. This is a site specific problem that needs to be analyzed for the impact it may have on BCAS operation in a particular area. Category C. 5c is also site specific and should be analyzed for the specific conditions.

TABLE IV. SELECTED ATCRBS CATEGORIES WITH POTENTIAL IMPACT ON BCAS PERFORMANCE

Category	Relevant Improvements	Potential Impact on BCAS	Action Required
A.3. Power Reduction	a) Reduce Power Level to Minimum Requirements b) Adjust Directional/OMNI Ratio to Required Standards	a) Reduce Coverage Area b) Reduce SLS Signal Detectability	a) Assess Impact on Coverage b1) SLS Signal Detectability
B.1. Parameter Optimization	a) Optimize, PRF, Scan Rate Mode Interlace	None (Unless Such Data is Used a Priori)	None (Update BCAS if Such Data is Used a Priori)
B.2. Improved Site Environment	a) Relocate Radar Site if Necessary		
C.1. Improved Antenna	a) Minimizes Vertical Lobing b) Incorporates Rotary Joint for Either "Integral" SLS or Monopulse Operation	a) Improves Reception b1) Impact of "Integral" SLS Unknown b2) Fewer Pulses/Scan Impact Unknown	b1) Assess Impact "Integral" SLS B2) Analyze Impact Monopulse Operation
C.5. Interrogator Modifications	a) Provides Stagger/Destagger Capability to All ATCBI-3 Stagger the Mode Interrogation Signals By at Least 25 usec. b) Azimuth Gate the Power Output or STC Curve to Reduce Site Specific Reflections and Synchronous Interference From Adjacent Overlapping a TCRB. c) Install False Target Suppression Transmitter (Trevose Fix) for ATCRB Sites with Well Defined Reflection Problem. System Consists of a Directional Horn and An SLS/ISLS Transmitter Used to Supress Aircraft Transponders in Area of Reflection and False Target Generation.	a) Improves Radar Selection/Discrimination b1) None for STC Gating b2) For Gated Power Radar Signals May-not be Available at Some Azimuth c) Unknown-(Intruder Aircraft May Not Respond-Blind Spot)	a) None (update BCAS if Such Data is Used a Priori) b2) Site Specific Study and Analysis Site Specific Study and Analysis

c) <u>ATCRBS SIGNAL STRUCTURE</u> C.1 IMPROVED ANTENNA (b1), (b2).

Category C.1 improvements, if implemented, may result in either "Integral" SLS and/or monopulse operation. The word "integral" implies that the phase centers of SSR main beam antenna and the omni-directional antenna will be the same. This should provide a better match between the main beam and the omni vertical lobing pattern. However, with an "Integral" SLS, the side lobe suppression signals may be available in a restricted azimuth only. Thus, an assessment needs to be made of the resultant potential impact on BCAS operation.

The impact of monopulse operation is also unknown and an assessment needs to be made to determine the impact of this modification on BCAS performance.

3. SUMMARY

The on-going improvements in the ATCRBS system were examined and their potential impact on BCAS operation assessed. The "selected" improvements that might impact on BCAS operation are summarized in Table V. Item 1 does not require any action since in the present design BCAS operation is <u>independent</u> of these improvements/modifications. Updating of BCAS file would be required only if such information were used a priori. Item 2 requires overall and some site specific coverage studies. Item 3 requires a) the assessment of "Integral" SLS on BCAS operation and b) an evaluation of monopulse operation on BCAS performance.

On the basis of the above examinations of the planned ATCRBS improvements/modifications, the two areas of potentially greatest impact on BCAS operation are 1) implementation of an "integral" antenna system and 2) monopulse operation in which fewer interrogations pulses per scan may be transmitted.

In the passive mode of operation, BCAS relies on the transmitted interrogation and SLS signals for acquisition, and tracking of ground radars, timing and bearing determination. Any such planned improvements/modifications that result in modification of these signal characteristics/patterns must therefore be thoroughly examined and evaluated.

TABLE V. SUMMARY OF SELECTED CATEGORIES WITH POTENTIAL IMPACT ON BCAS OPERATION

Category	Relevant Improvements	Potential Impact on BCAS	Action Required
1. B.1 Paramater Optimization	Optimize, PRF, Scan Rate, Mode Interlace	Beneficial	None (Update BCAS File if Such Information is Used a Priori)
B.2 Improve Site Enviroment	Relocate Radar Site if Necessary	Beneficial	
C.5 (a) Interrogator Modifications	a) Provide PRF Stagger Destagger/ Capability	a) Improves Radar Identification/Discrimination	
2. A.3 (a) Power Reduction	a) Reduce Power to Minimum Requirements	a) Reduces Coverage Area	a) Assess Impact on Coverage-Range of SLS Signals.
C.5 (b)(c) Interrogator Modifications	b) Azimuth Gate Power Output c) Trevose Fix	b) Reduce coverage at Some Azimuth c) Suppresses Transponder Replies at Some Azimuth-Impact Unknown	b) Site Specific Coverage Analysis c) Site Specific Study and Analysis
3. C.1 (b) Improved Antenna	b1) "Integral" SLS b2) Monopulse Operation	b1) Unknown-Signals Radiate in Restricted Azimuth. b2) Unknown-Fewer Pulses Per Scan	b1) Assess Impact of antenna pattern b2) Assess Impact of Monopulse Operation

APPENDIX B. FLIGHT TEST PATTERNS

PATTERN #1 - One or more aircraft. Approximately a 50 NM track along low altitude airway V467 in the vicinity of Millville, New Jersey. This airway utilizes the 047° radial and the 226° radial of the Millville VORTAC, MIV, frequency 115.2, channel 99. Airspace required: 30 NM NE to 20 NM SW. Altitudes, between 3500 feet and 21,000 feet.

PATTERN #2 - One or more aircraft utilizing the basic fix at Millville, New Jersey VORTAC, radial 040° - 055° - 220° - 235° (Figure B-1).

Radius of action can vary to that desired for data collection purposes. Airspace altitude required same as Pattern #1. This pattern can be displaced and/or rotated to any basic fix at any location based on test requirements. Once aircraft are established in basic figure eight, the pattern remains the same until test requirements dictate otherwise.

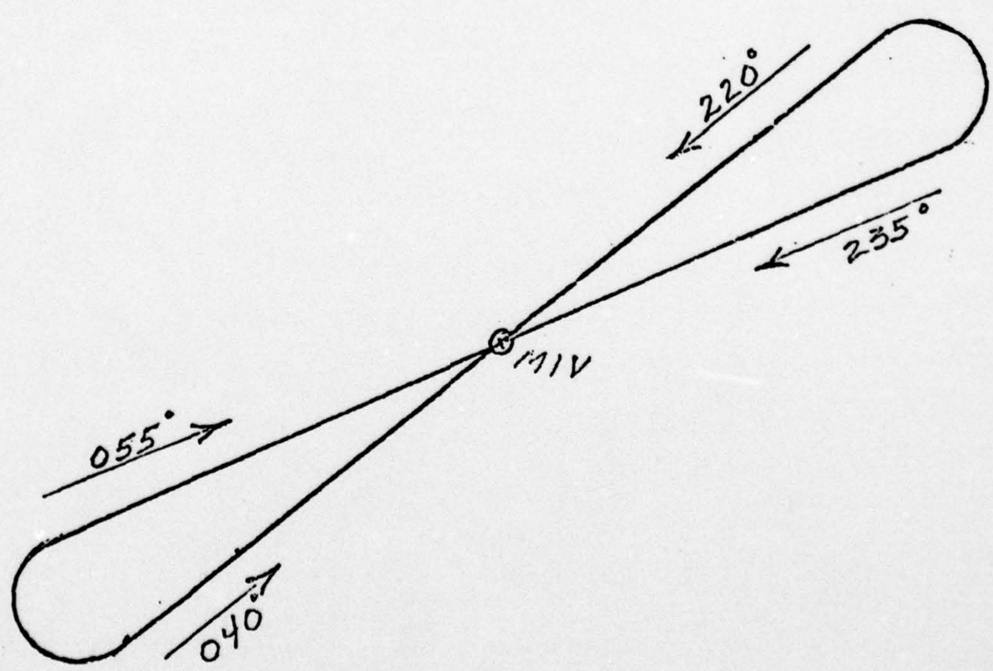


FIGURE B-1. PATTERN #2

PATTERN #3 - This pattern requires orbits, clockwise or counter-clockwise around the modified beacon sites at Atlantic City, Philadelphia, and Newport (see test geometry chart). Radius of orbit and altitudes will vary according to data collection and test requirements. As other sites are modified, the pattern can be flown at those locations, subject to airspace approval.

PATTERN #4 - This pattern can be flown by one or more aircraft and is normally used to obtain maximum lock/unlock information. Aircraft fly the normal enroute airway, V139, at various altitudes and shuttle between maximum and minimum (unlock/lock) range up to approximately 200 NM from NAFEC. The magnetic track from Atlantic City is approximately 216°. Maximum distance is in the vicinity of Norfolk, Virginia.

NOTE - These are the four basic patterns used in debugging and actual data collection flights.

PATTERN #5 - This pattern will be used for multiple aircraft encounters within a 12 NM radius of the Millville VORTAC; however, it can be adapted for use over any VOR/DME fix. This is a modified rotating Double Daisy with each aircraft turning 30° in opposite directions to achieve encounters over the fix in 60° increments. Vertical separation between aircraft will be 400 feet and base altitude can vary between the low stratum of 3000 to 15,000 feet, or the high stratum between 18,000 feet and 23,000 feet. Planned leg distance is 8 NM plus turn radius. It is desired that 12 runs be flown at three different altitudes, low, medium and high. Twelve runs will provide ± 180° of coverage twice, for repeatability data (See Figure B-2).

TABLE B-1. PATTERN #5

ENCOUNTER	HDG. A/C #1	HDG. A/C #2	INTRCPT ANGLE
1	270	090	180
2	060	300	120
3	210	150	60
4	360	360	0
5	150	210	60
6	300	060	120
7	090	270	180
8	240	120	120
9	030	330	60
10	180	180	0
11	330	030	60
12	120	240	120

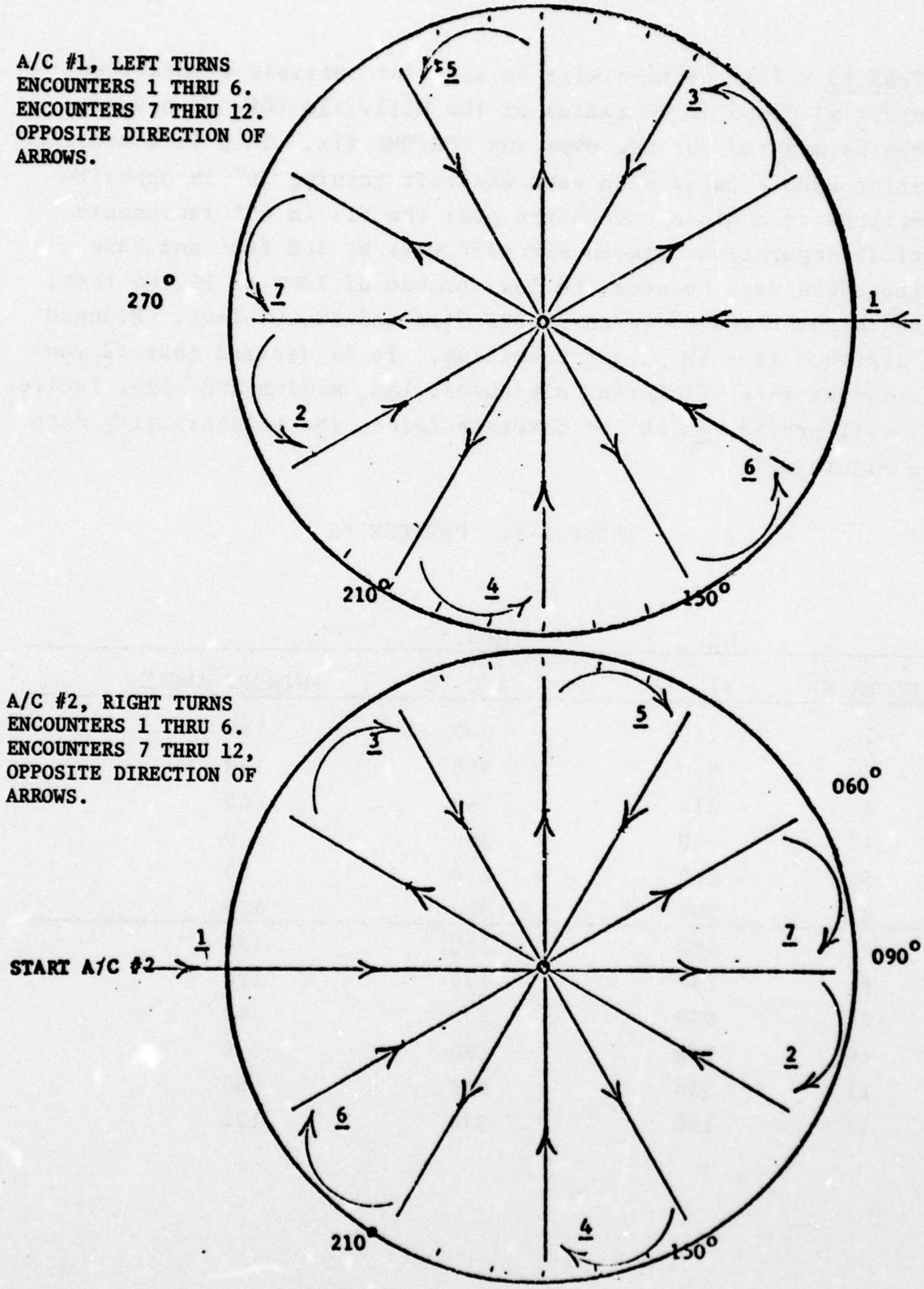


FIGURE B-2. PATTERN #5

PATTERN #6 - This pattern will be used for two aircraft to obtain radial environment data between the two modified radars located at Atlantic City and Philadelphia, a one-way distance of 30 NM. Aircraft #2 will be positioned 4 NM behind and 4 NM to the right of Aircraft #1. Three round trip patterns will be flown, one at each of three altitudes, 2000, 10,000, and 20,000 feet, ± 500 feet.

PATTERN #7 - This pattern will be flown by two aircraft to determine multipath effects on the system performance. Altitude between aircraft will be 400 feet to 800 feet vertically with the basic altitude at three levels, 4000, 10,000 and 15,000 feet, ± 500 feet. Radius of operation will be within approximately 15 NM of the Millville VORTAC. Aircraft without RNAV equipment will utilize DME and radials from the Millville VORTAC. Special requirements for the test are dry land conditions. Pattern shown in Figure B-3.

TABLE B-2. PATTERN #6 AND #7

POINT	DME FR FIX	N.M. SPRTN	HDG. A/C #1	HDG. A/C #2
0	6.9	0.5	180°	180°
1	3.9	0.5	Turn	Turn
2	3.2	2.5	090°	270°
3	4.4	6.5	Turn	Turn
4	4.7	8.5	180°	180°
5	6.0	8.5	Turn	Turn
6	6.5	10.5	090°	270°
7	8.5	16.5	Turn	Turn
8	8.5	16.5	290°	070°
9	2.5	5.0	Turn	Turn
10	1.5	3.0	360°	360°
11	7.1	3.0	Turn	Turn

PATTERN #8 - This pattern is identical to that described in pattern #7 with the exception that special requirements dictate the accomplishment over smooth water. Probable flight areas would be over the Atlantic Ocean in warning areas 107 or 108, or over the Delaware Bay. If RNAV is not available, DME/Radial from the Atlantic City, Kenton, Sea Isle, Waterloo VORS or Dover TACAN would have to be used for positioning. Pattern is shown in Figure B-3.

TABLE B-2. PATTERN #6 and 7 APPLIES TO PATTERN #8 (Cont.)

POINT	DME FR FIX	N.M. SPRTN	HDG. A/C #1	HDG. A/C #2
0	6.9	0.5	180°	180°
1	3.9	0.5	Turn	Turn
2	3.2	2.5	090°	270°
3	4.4	6.5	Turn	Turn
4	4.7	8.5	180°	180°
5	6.0	8.5	Turn	Turn
6	6.5	10.5	090°	270°
7	8.5	16.5	Turn	Turn
8	8.5	16.5	290°	070°
9	2.5	5.0	Turn	Turn
10	1.5	3.0	360°	360°
11	7.1	3.0	Turn	Turn

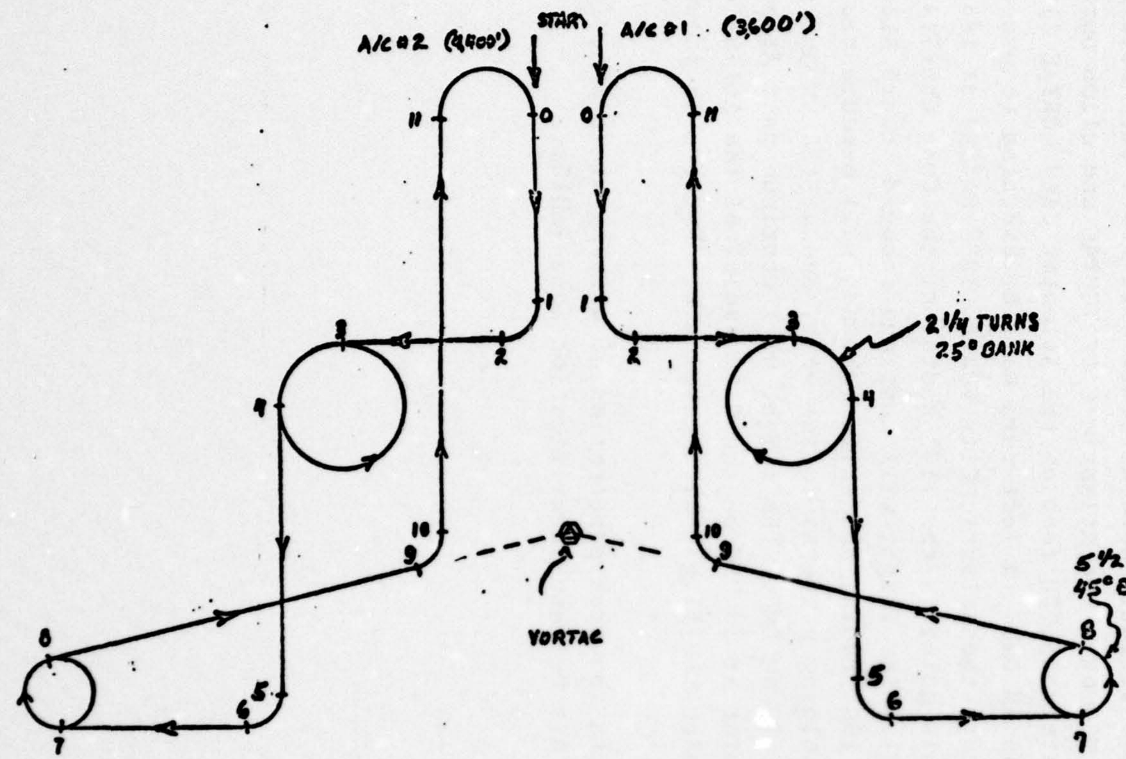


FIGURE B-3. PATTERN #7

PATTERN #9 - This pattern requires two aircraft capable of altitude operation at 20,000 feet or better. Aircraft #2 will be positioned one NM to the rear and 400 feet above aircraft #1. throughout the flight. Both aircraft will start the pattern at 10,000 feet MSL over the Atlantic City VORTAC and climb outbound to approximately 23,000 feet on the Atlantic City VORTAC 216° radial to 145 NM DME. A left turn will be executed to proceed so as to intercept the Atlantic City VORTAC 190° Radial at 145 NM DME. (This point is the 112° Radial of the Cape Charles VORTAC at 71 NM DME). The flight will continue inbound toward Atlantic City on the 190° radial and while inbound, will execute two one (1) minute holding patterns to the west; one at 120 NM DME and the other at 70 NM DME. The flight will continue past Atlantic City to a point at 30 DME on the 010° radial of the Atlantic City VORTAC at which the flight will terminate. Pattern is shown in Figure B-4.

NOTE: Pattern requires penetration of warning areas 386, 107 and 108 and the Air Defense Identification Zone (ADIZ).

Warning Area Penetration:

W-386: from 26 nm DME CCV (112°R)
at 75° 30.0'W 37° 11.0'N
East to 71 DME CCV (112°R), turn North
at 74° 34.0'W 37° 04.5'N
Holding pattern orbit at 120 nm DME ACY
at 74° 34.1'W 37°28.8'N

W-108: (leave W-386): 88 nm DME ACY (190°R)
at 74° 34.2'W 38° 00.0'N
Holding pattern orbit at 70 nm DME ACY
at 74° 34.2'W 38° 18.0'N
Leave W-108 42 nm DME ACY
at 74° 34.3'W 38° 45.0'N

W-107: From 20 nm DME ACY (109°R)
at 74° 34.4'W 39° 07.0'N
Leave W-107 15 nm° DME ACY
at 74° 34.4'W 39° 12.3'N

Atlantic Coastal ADIZ: From 32 nm DME CCV (112°R)
at 75° 23.7'W 37° 09.3'N
Leave ADIZ at 67 nm DME ACY (190°R)
at 74° 34.3'W 38° 21.3'N
And momentarily during second holding orbit

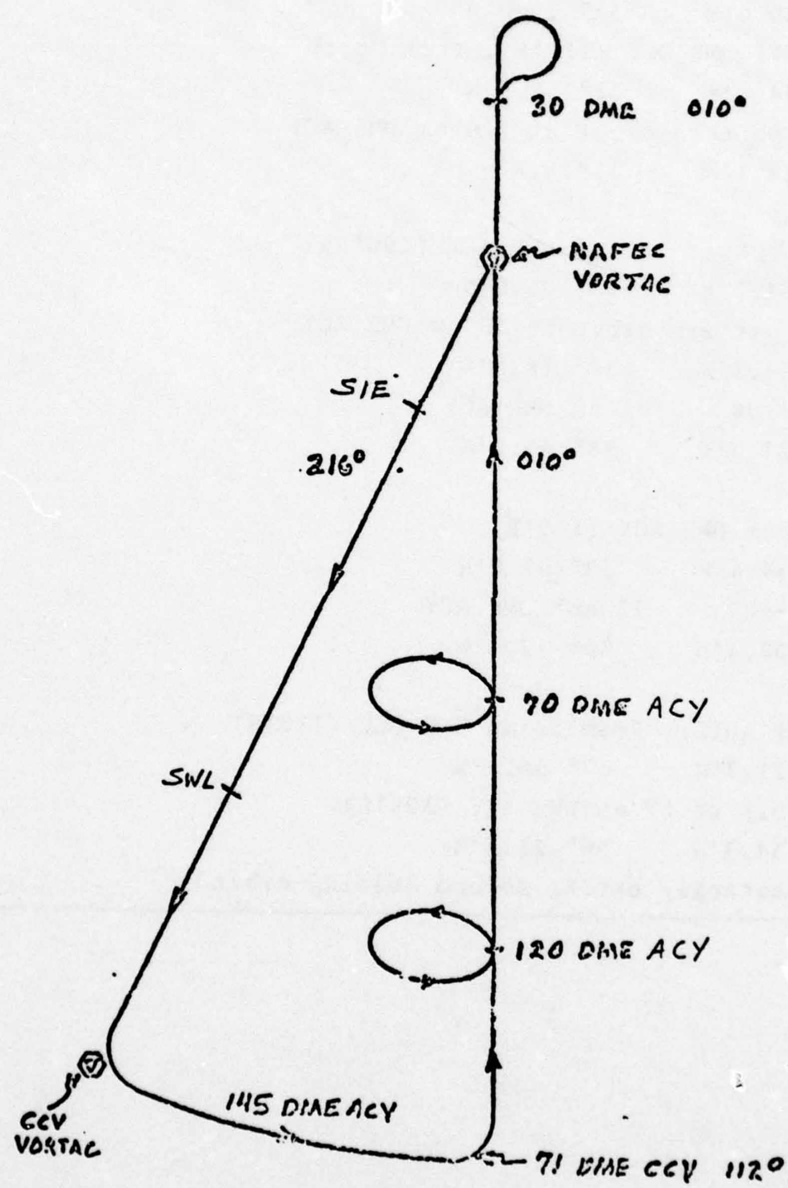


FIGURE B-4. PATTERN #9

PATTERN #10 - Rotating Double Daisy similar to PATTERN #5 except encounter angles are 30° instead of 60°. Aircraft #1 will execute all turns to the left and Aircraft #2 will execute all turns to the right. Aircraft #1 commences flying from 10 NM west of the VORTAC ground station to 10 NM east of the VORTAC station. While inbound to the station from the west, the bearing is 090°, which is the magnetic course he must fly to reach the station. After passing the station and continuing eastward, his VORTAC bearing is 270°. Upon reaching a point 10 NM east of the station, the pilot executes a 195° turn to the left, intercepting and positioning the aircraft inbound on the 075° radial of the station, or a bearing of 255°. After each traverse of the VORTAC station, at the 10 NM point, the pilot again executes a 195° turn to acquire a bearing to or a radial from the VORTAC station displaced 15° from the previous one. This process continues for a total of 12 transverses of the VORTAC station to complete 360° of coverage.

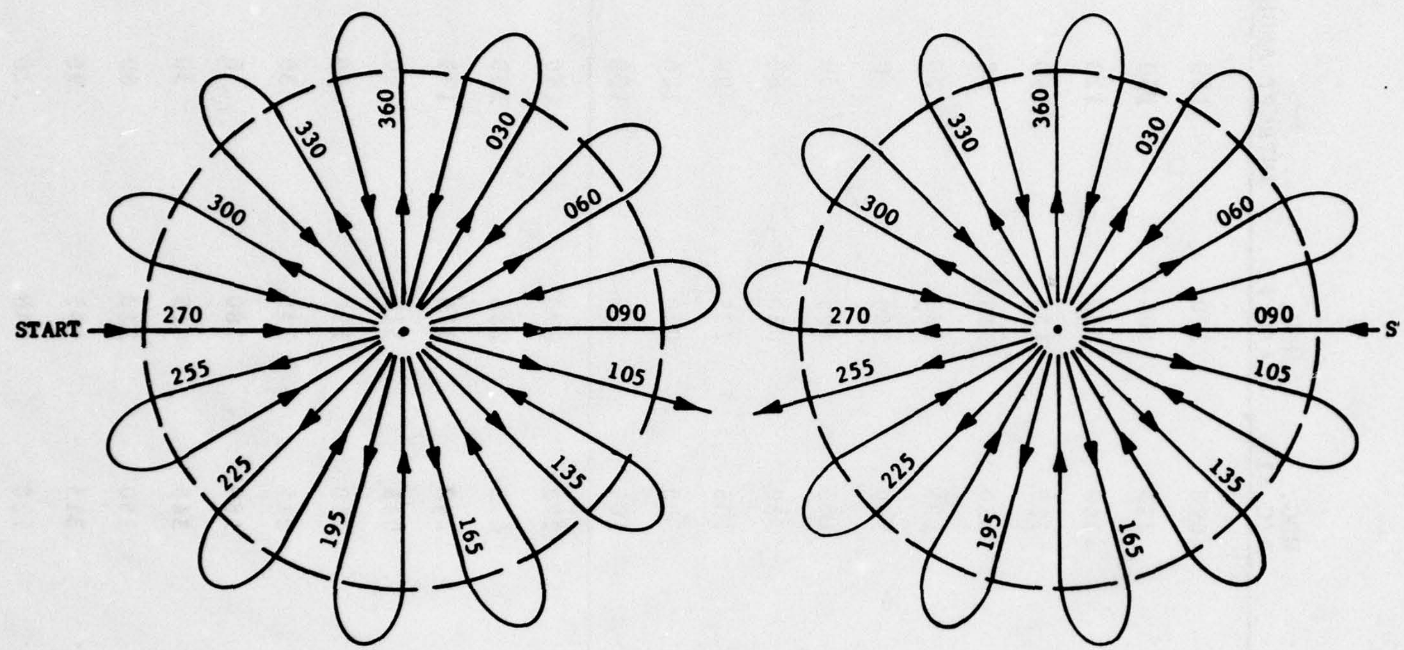
Aircraft #2 starts the pattern flying from 10 NM east of the VORTAC ground station to 10 NM west of the VORTAC station. While inbound to the station from the east, his bearing is 270°, which is the magnetic course he must fly to reach the station. After passing the station and continuing west bound, his bearing is 090°. Upon reaching a point 10 NM west of the station, the pilot executes a 195° right turn, intercepting and positioning the aircraft inbound on the 285° radial of the station, or a bearing of 105°. After each traverse of the station, at the 10 NM point, the pilot again executes a 195° right turn to acquire a bearing to or a radial from the VORTAC station displaced 15° from the previous one. This process, as that of aircraft #1, continues for a total of 12 traverses of the VORTAC station of complete 360° of coverage.

Usually this pattern requires both aircraft to maintain a constant airspeed, normally 150K, with 400 feet of vertical separation. The exceptions are runs numbered 7 and 19, which are tail-chase runs. During a tail-chase, aircraft #2 will increase speed to 230K and start the turn-in at a point 14.3 NM from the station instead of 10 NM. Aircraft #1 is designated as the control aircraft and

calls each mile mark during each run. This allows Aircraft #2 to adjust speed so as to expect crossovers directly over the VORTAC station. (See Figure B-5).

As can be seen looking at Table B-3, this sort of pattern provides positive and negative intercept angle throughout a 360° azimuth area in 30° increments.

PATTERN #11 - Two aircraft will be used for this pattern with the standard 400 feet vertical separation between aircraft. Normal operating area will be in the vicinity of the Millville VORTAC within a radius of 15 NM at an altitude above 9500 feet MSL. There are four types of encounter patterns to be flown, osculating (kissing), intersecting, coincident and reverse osculating. Eight of each type will be flown, for a total of thirty-two patterns with varying bank angles of 15°, 30°, 45°, and 60°, flown on each type. (60° bank angle exceeds that authorized for transport type aircraft, which is 45°). Pattern is shown in Figure B-6 and Table B-4.



A/C #1, LEFT TURNS.
ENCOUNTERS 1 THRU 12.
ENCOUNTERS 13 THRU 24
OPPOSITE DIRECTION OF
ARROWS.

A/C #2, RIGHT TURNS.
ENCOUNTERS 1 THRU 12.
ENCOUNTERS 13 THRU 24
OPPOSITE DIRECTION OF
ARROWS.

FIGURE B-5. PATTERN #10

TABLE B-3. PATTERN #10

#10	ENCOUNTER	HDG. A/C #1	HDG. A/C #2	INTRCPT ANGLE
	1	090	270	180
	2	255	105	150
	3	060	300	120
	4	225	135	90
	5	030	330	60
	6	195	165	30
	7	360	360	0
	8	165	195	30
	9	330	030	60
	10	135	225	90
	11	300	060	120
	12	105	255	150
	13	270	090	180
	14	075	285	150
	15	240	120	120
	16	045	315	90
	17	210	150	60
	18	015	345	30
	19	180	180	0
	20	345	015	30
	21	150	210	60
	22	315	045	90
	23	120	240	120
	24	285	075	150

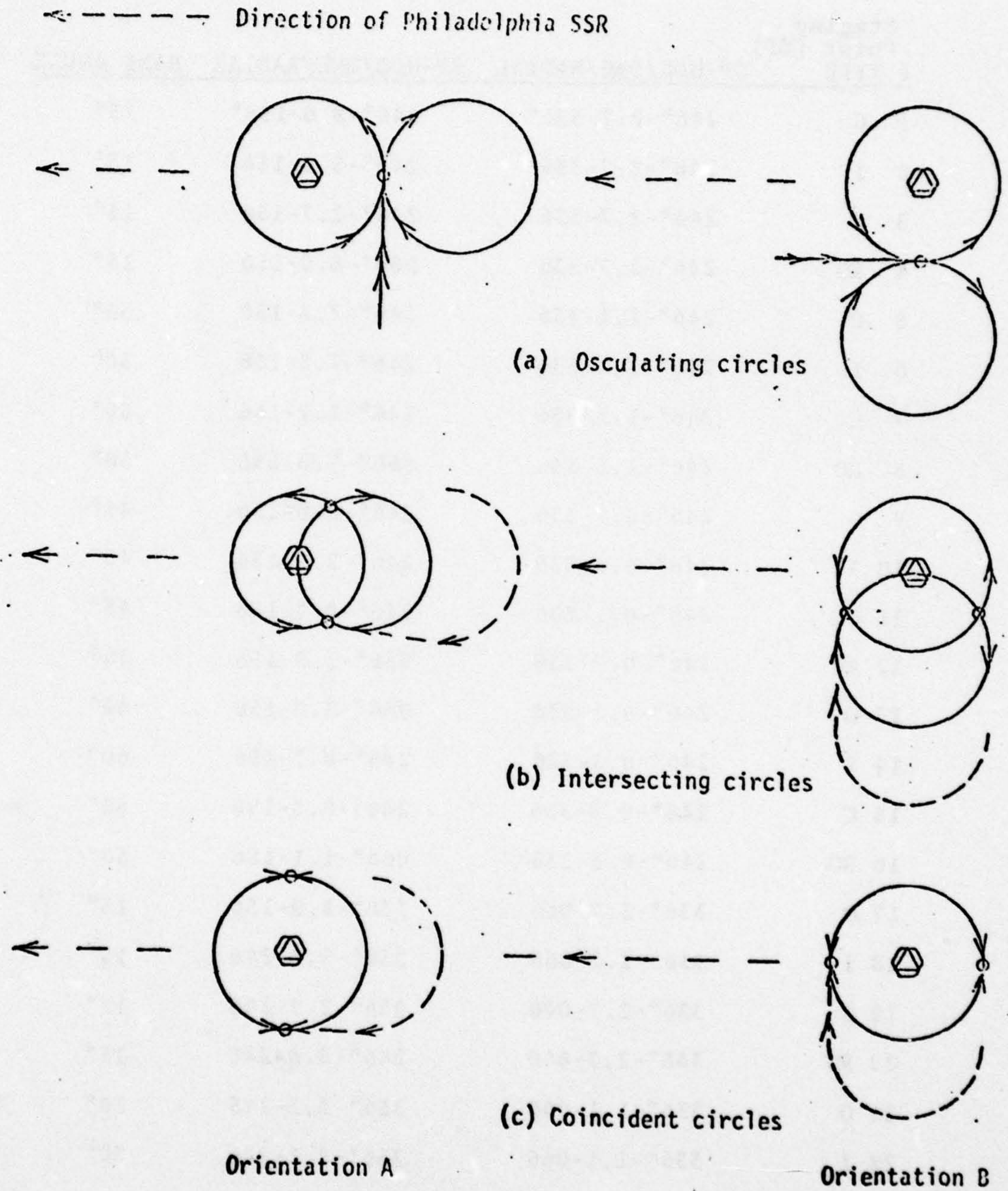


FIGURE B-6. PATTERN #11

TABLE B-4. PATTERN #11

#	Staging Point (SP) TYPE	SP-HDG/DME/RADIAL	SP-HDG/DME/RADIAL	BANK ANGLE
1	O	246°-2.7-336°	246°-8.0-156°	15°
2	I	246°-2.7-336°	246°-5.3-156	15°
3	C	246°-2.7-336	246°-2.7-156	15°
4	RO	246°-2.7-336	066°-8.0-156	15°
5	O	246°-1.1-336	246°-3.3-156	30°
6	I	246°-1.1-336	246°-2.2-156	30°
7	C	246°-1.1-336	246°-1.1-156	30°
8	RO	246°-1.1-336	066°-3.3-156	30°
9	O	246°-0.7-336	246°-2.0-156	45°
10	I	246°-0.7-336	246°-2.0-156	45°
11	C	246°-07.-336	246°-0.7-156	45°
12	RO	246°-0.7-336	066°-2.0-156	45°
13	O	246°-0.7-336	066°-2.0-156	60°
14	I	246°-0.3-336	246°-0.7-156	60°
15	C	246°-0.3-336	246°-0.3-156	60°
16	RO	246°-0.3-336	066°-1.1-156	60°
17	O	336°-2.7-066	336°-8.0-156	15°
18	I	336°-2.7-066	336°-5.3-246	15°
19	C	336°-2.7-066	336°-2.7-246	15°
2)	RO	336°-2.7-066	246°-8.0-246	15°
21	O	336°-1.1-066	336°-3.3-246	30°
22	I	336°-1.1-066	336°-2.2-246	30°

TABLE B-4. PATTERN #11 (CONT.)

#	Staging Point (SP) TYPE	SP-HDG/DME/RADIAL	SP-HDG/DME/RADIAL	BANK ANGLE
23	C	336°-1.1-066	336°-1.1-246	30°
24	RO	336°-1.1-066	246°-3.3-246	30°
25	O	336°-0.7-066	336°-2.0-246	45°
26	I	336°-0.7-066	336°-1.3-246	45°
27	C	336°-0.7-066	336°-0.7-246	45°
28	RO	336°-0.7-066	246°-2.0-246	45°
29	O	336°-0.3-066	336°-1.1-246	60°
30	I	336°-0.3-066	336°-0.7-246	60°
31	C	336°-0.3-066	336°-0.3-246	60°
32	RO	336°-0.3-066	246°-1.1-246	60°

PATTERN #12 - See Figure B-7. Two aircraft will be required for the climb-dive tests. Normal operating area will utilize the basic figure eight pattern using the Millville VORTAC radials 040°, 055° - 220° - 235° with legs ± 10 NM in length. Altitude will vary ±2000 feet of an optional basic altitude. Maneuvering aircraft, Aircraft #1 and/or Aircraft #2, when changing altitude will establish a change rate of 2000 feet per minute with lateral separation of one-half NM or less during vertical cross-overs. The two basic patterns will be head-on and same direction parallel flights. In each type, runs will be made with one aircraft level while the other is climbing and diving and with both aircraft climbing and diving simultaneously in opposite vertical directions.

Type of encounters within figure eight:

A. PARALLEL. A/C #1 remains level at 8000'. A/C #2 initially at 10,000'. Will descend to 6000' NE BOUND. Will climb from 6000' to 10,000' SW BOUND. (approximately 2 to 4 runs).

B. PARALLEL. A/C #1 climbs from 6000' to 10,000' SW BOUND, A/C #2 descends from 10,000' to 6000' SW BOUND. NE BOUND A/C reverse. A/C #1 descends from 10,000' to 6000' and A/C #2 climbs from 6000' to 10,000' (approximately 2-4 runs).

C. HEAD-ON. A/C #1 remains level at 8000: A/C #2 will descend from 10,000' to 6000' NE BOUND, and climb from 6000' to 10,000 SW BOUND. A/C will utilize opposite radials toward each other (approximately 2-4 runs).

D. HEAD-ON. Both A/C will climb and descend between 10,000' and 6000'. When A/C #1 is descending, A/C #2 will be climbing & vice versa. (Approximately 4 to 6 runs).

NOTE: Actual leg lengths will probably be within ± 10nm of the station, to allow aircraft to position themselves for X-overs at the station at 2000 FPM rate of climb or descent.

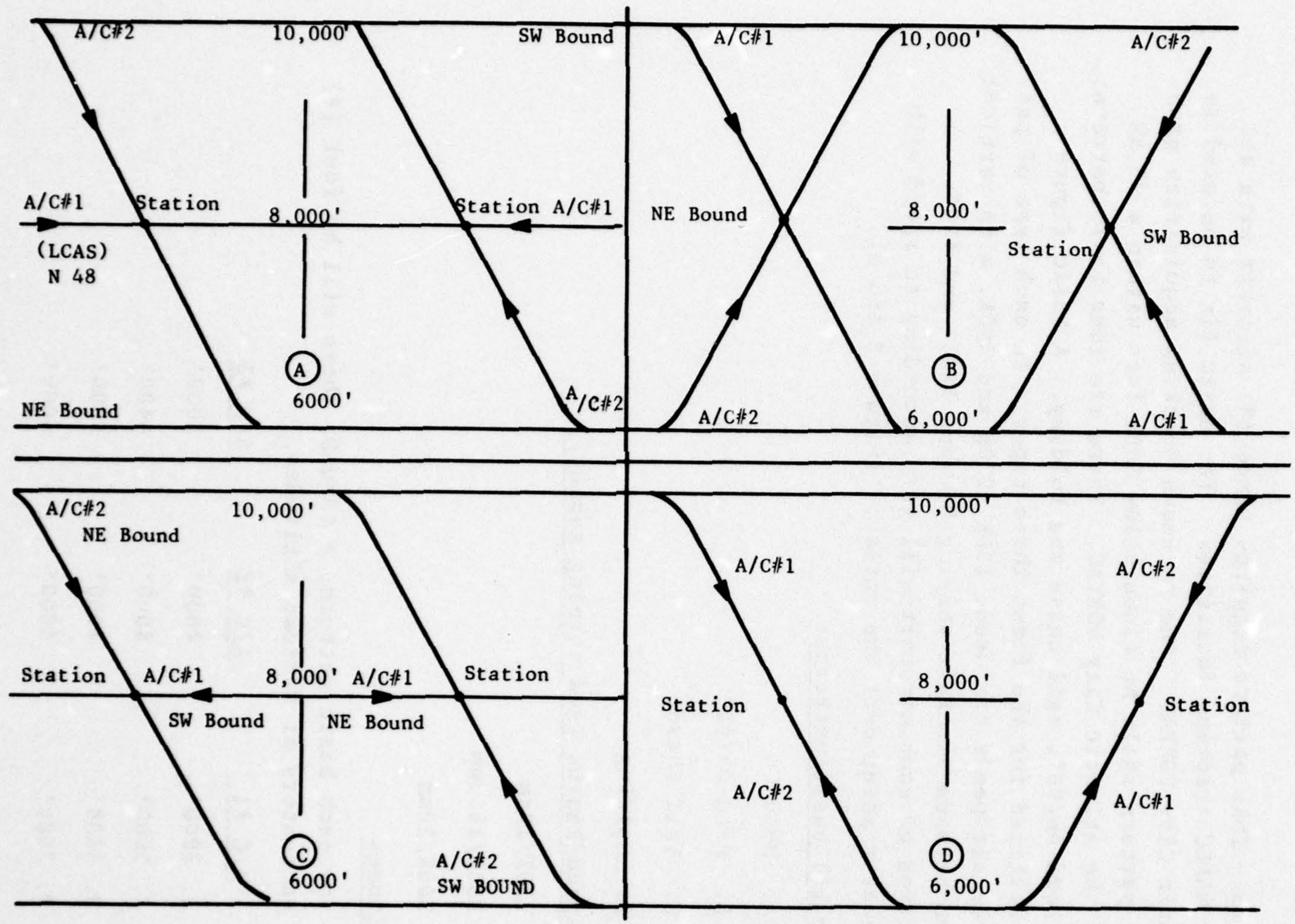


FIGURE B-7. PATTERN #12

PATTERN #13 - This pattern requires three (3) aircraft with all available NAFEC tracking facilities. The basic fix to be used is the Atlantic City VORTAC. Due to known tracking acquisition problems, the pattern shall be flown below 5000 feet within a 20 NM radius of the Atlantic City VORTAC. There are four basic patterns, head-on, head-on/90°, tail chase and holding. A basic figure eight is utilized for the first three types. In each type of pattern, three airspeeds are used, 150K, 230K and 300K, with vertical separation between aircraft varying between 1000' and 400'. Radius action of each aircraft will vary according to speed with the cross-over point over the vortac. (Figure 8 and 9).

Four (4) basic patterns:

A. Head-On

B. Head-On/90°

C. Tail Chase

D. Holding

Airspeed/Radius (Add turning radius)

150K/10nm

230K/15.3nm

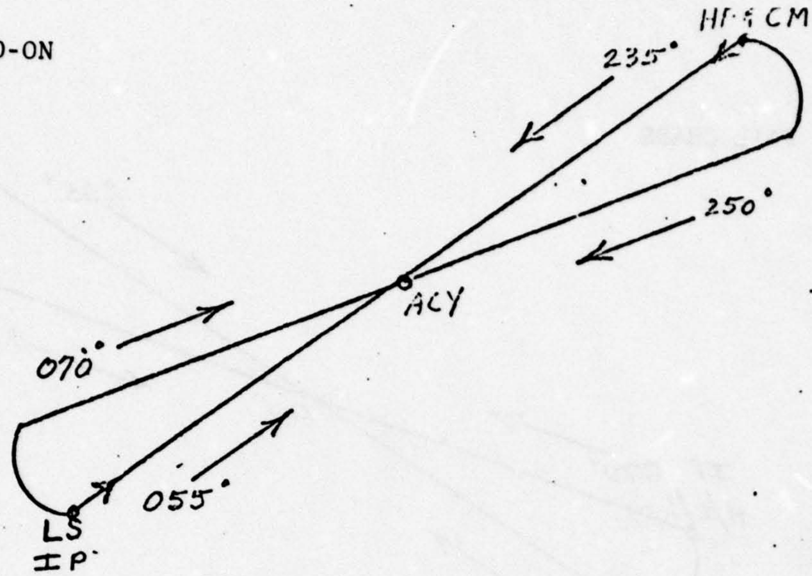
300K/20nm

Altitudes

For each basic pattern, A thru D, there will be four (4) encounters at various altitudes.

	A/C #1	A/C #2	A/C #3
1.	3000'	4000'	5000'
2.	3000'	4000'	4400'
3.	3600'	4000'	5000'
4.	3600'	4000'	4400'

HEAD-ON



HEAD-ON/90

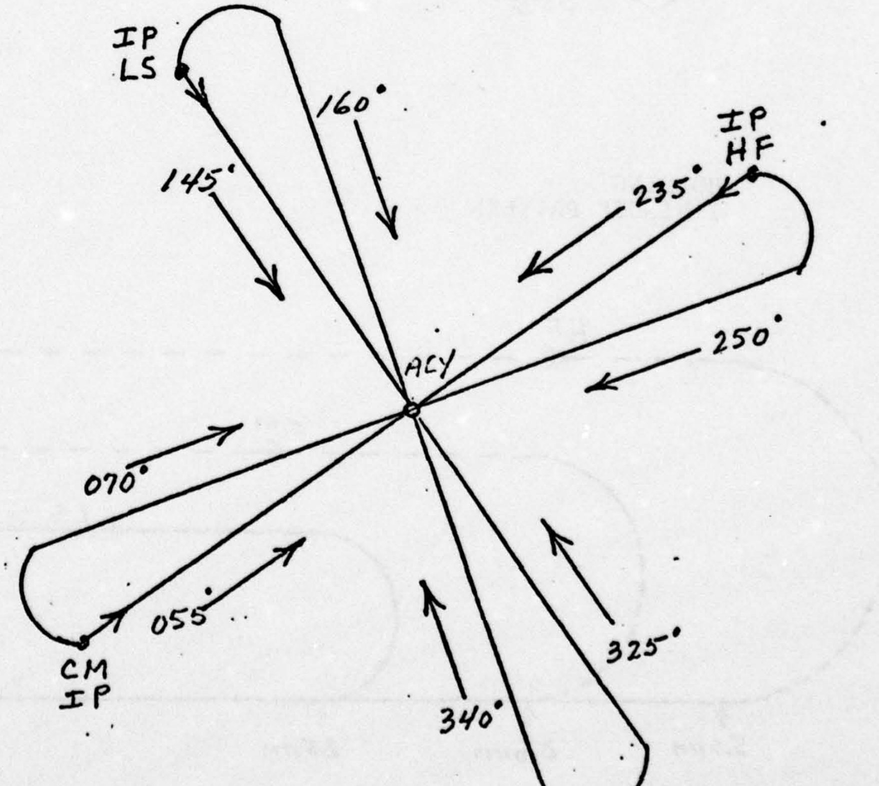
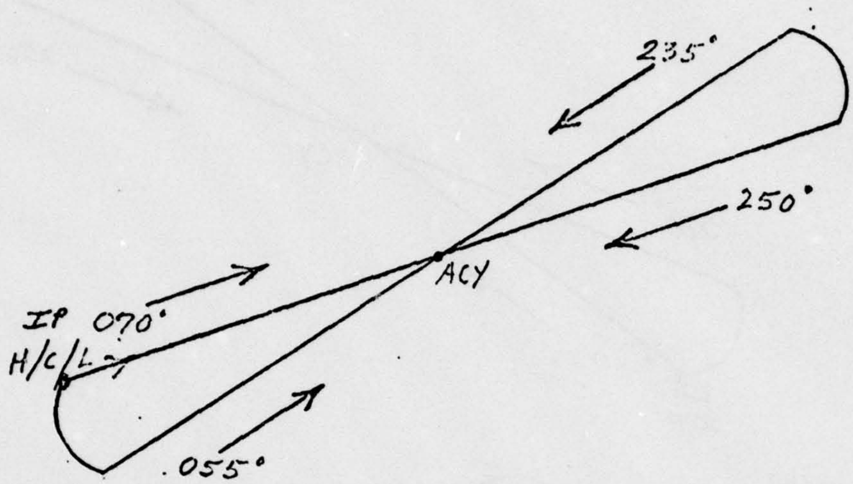


FIGURE B-8. PATTERN #13 (HEAD-ON, HEAD-ON/90°)

TAIL CHASE



HOLDING
1 MINUTE PATTERN

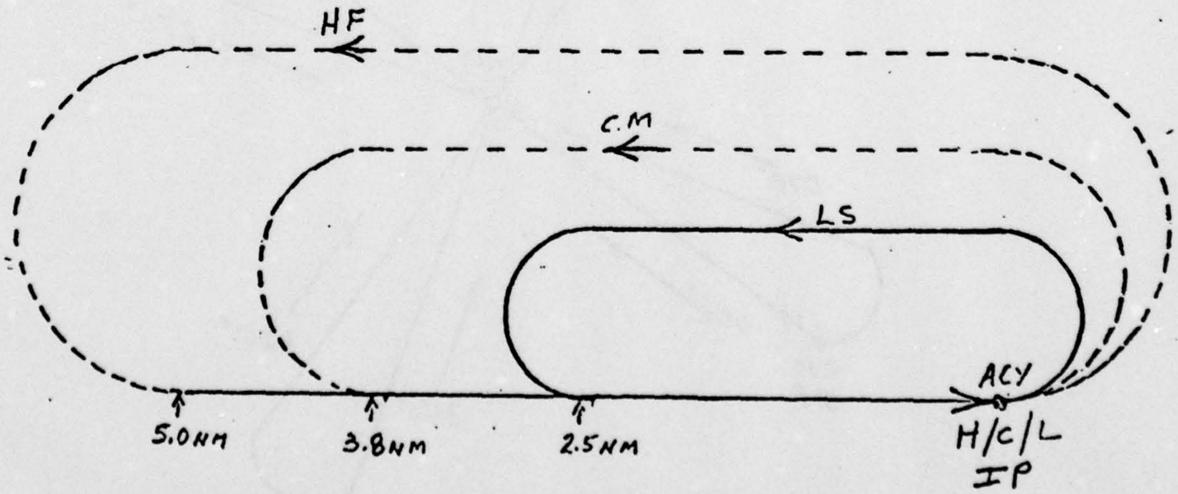


FIGURE B-9. PATTERN #13 (TAIL CHASE, HOLDING)

1. Heading 004° 30nm S to 30nm N of PHL

2. Heading 184° 30nm N to 30nm S of PHL

3. Heading 184° 30nm N to 30nm S of TVS

4. Heading 004° 30nm S to 30nm N of TVS

5. Heading 184° 30nm N to 30nm S of ACY

6. Heading 004° 30nm S to 30nm N of ACY

7. Heading 227° 30nm NE to 30nm SW of MIV (V467)

8. Heading 046° 30nm SW to 30nm NE of MIV (467)

9. Heading 080°-090° from OOD to 50nm East

10. Heading 260°-270° from 50nm East to OOD

11. Heading 184° 30nm N to 30nm S of NPT

12. Heading 004° 30nm S to 30nm N of NPT

When coordination is initiated for these tests, PATTERN #14 will be referred to, with the flight path desired given by numerical sequence of events required for data acquisition. Altitude desired and any deviation from those shown will be coordinated and clarified during the original request call.

<u>EXAMPLE:</u> Previous flights have been conducted IFR at 4000' and 5000' as follows: 13-1-2-13-5-6-7-8-13, or ACY 13 to 1 30 S of PHL to 30 N of PHL, 2 30 N of PHL to 30 S of PHL, 13 to ACY, 5 to 20 N of ACY to 20 S of ACY, 6 20 S of ACY to 20 N of ACY, 7 30 NE MIV to 20 SW MIV, 8 20 SW MIV to 30 NE of MIV, 13 to ACY-terminate. NOTE: 5-6-7-8 deviated from the 30nm to the 20nm points. This in some instances will produce the required results, and would be noted during the initial coordination call.

One proposed plan, when Trevose is modified, will be as follows: 13-1-31-3-5-6-7-8-13. The flight path is on Figure B-10.

The flight plan request would be as follows: ACY 13 to 1, 30nm S of PHL to 30nm N of PHL, to 3 30 N of TVS to 30 S of TSV, to 1

AIRCRAFT: Initial Start Point = IP

ALTITUDE	AIRSPEED
High = H	Fast = F
Center = C	Medium = M
Low = L	Slow = S

PATTERN #14. North Pulse Kit Installation & Interface Tests. Kits are or will be installed on radars at Philadelphia, Trevose, Atlantic City and Newport (mobile). ACY is shown on Figure B-10 at 0 mileage point of North/South radials, 004° & 184°.

Patterns usually consist of ± 30nm of site, on a magnetic track of 004° & 184° (North pulse beam width is 8° wide, from 0° cw to 008°).

When all four kits are installed, patterns are desired N&S each site, plus 30NM NE and 30NM SW of MIV on V467. In addition, a radial off of OOD may be required, either the 080° R or 090°R to a point 50nm East.

The OOD and MIV radials are required to bisect the radar positions at various angles to acquire the requested test data.

Explananation of numbers on Figure B-10

NUMBER		
13.	Atlantic City	ACY
14.	Newport	NPT
15.	Philadelphia	PHL
16.	Trevose	TVS
17.	Millville	MIV
18.	Woodstown	OOD

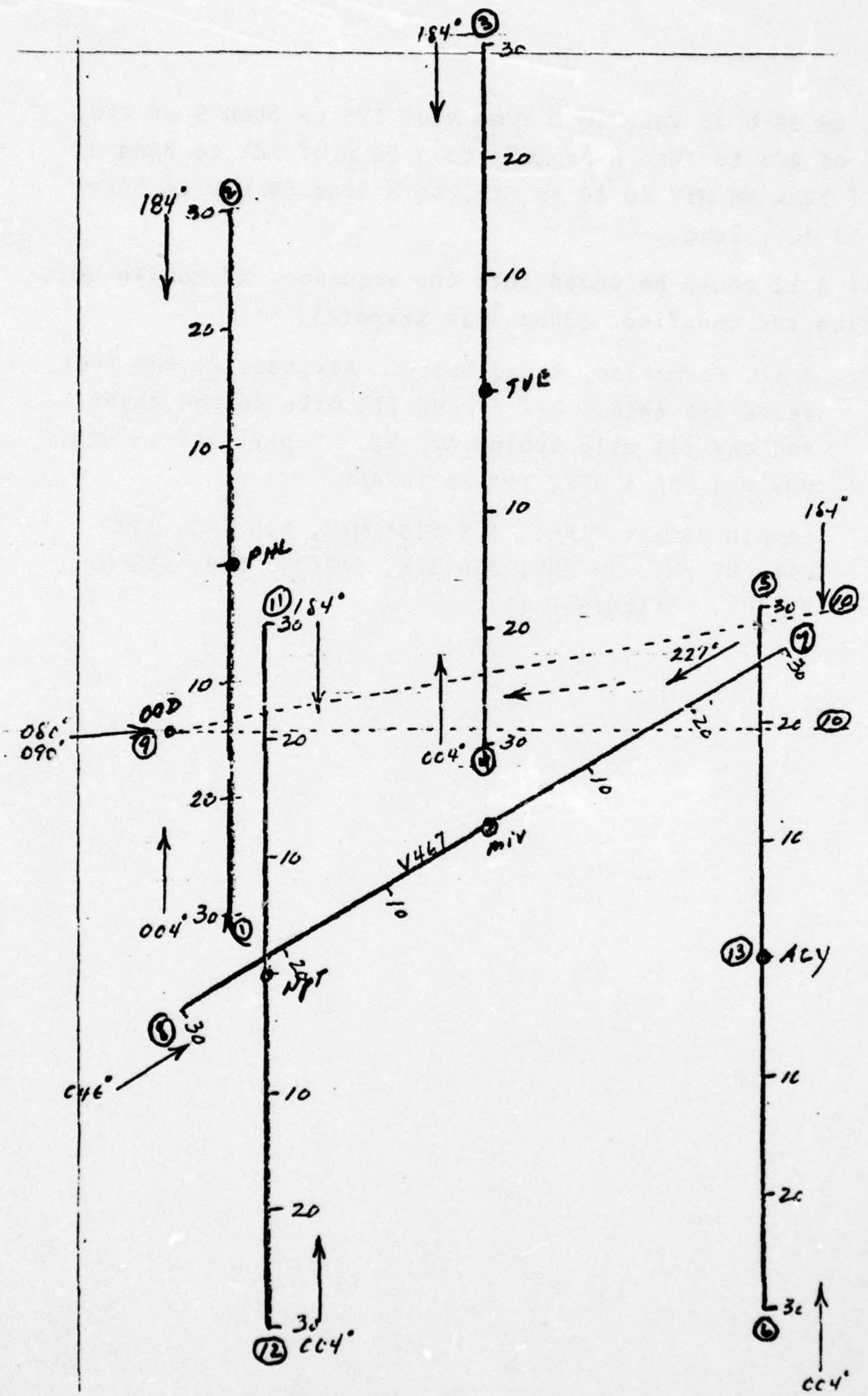


FIGURE B-10. PATTERN #14

30 S of PHL to 30 N of PHL, to 3 30nm N of TVS to 30nm S of TVS, to 5 30nm N of ACY to 30nm S of ACY, to 6 30 S of ACY to 30nm N of ACY, to 7 30nm NE MIV to 30 SW MIV, to 8 30nm SW MIV to 30nm NE MIV, to 13 ACY, land.

Runs 11 & 12 could be added into the sequence, if mobile unit is in position and modified. (30nm $\pm$ 14 Newport).

PATTERN #15. 2 A/C Formation, Round-Robin. Altitude 24,000 Feet Speed 250 KWTS. A/C #2 one (1) mile to the right and one (1) mile behind A/C #1. Depart ACY to DCA, BOS via PHL & JFK, return to ACY.

Sample Flight Plan: ACY V184 MIV, V16 ENO, J37 OTT, RV EMI, J6 RBV, J80 JFK, J48/J77 BOS, J55 SIE, RV ACY. (Figure B-11).

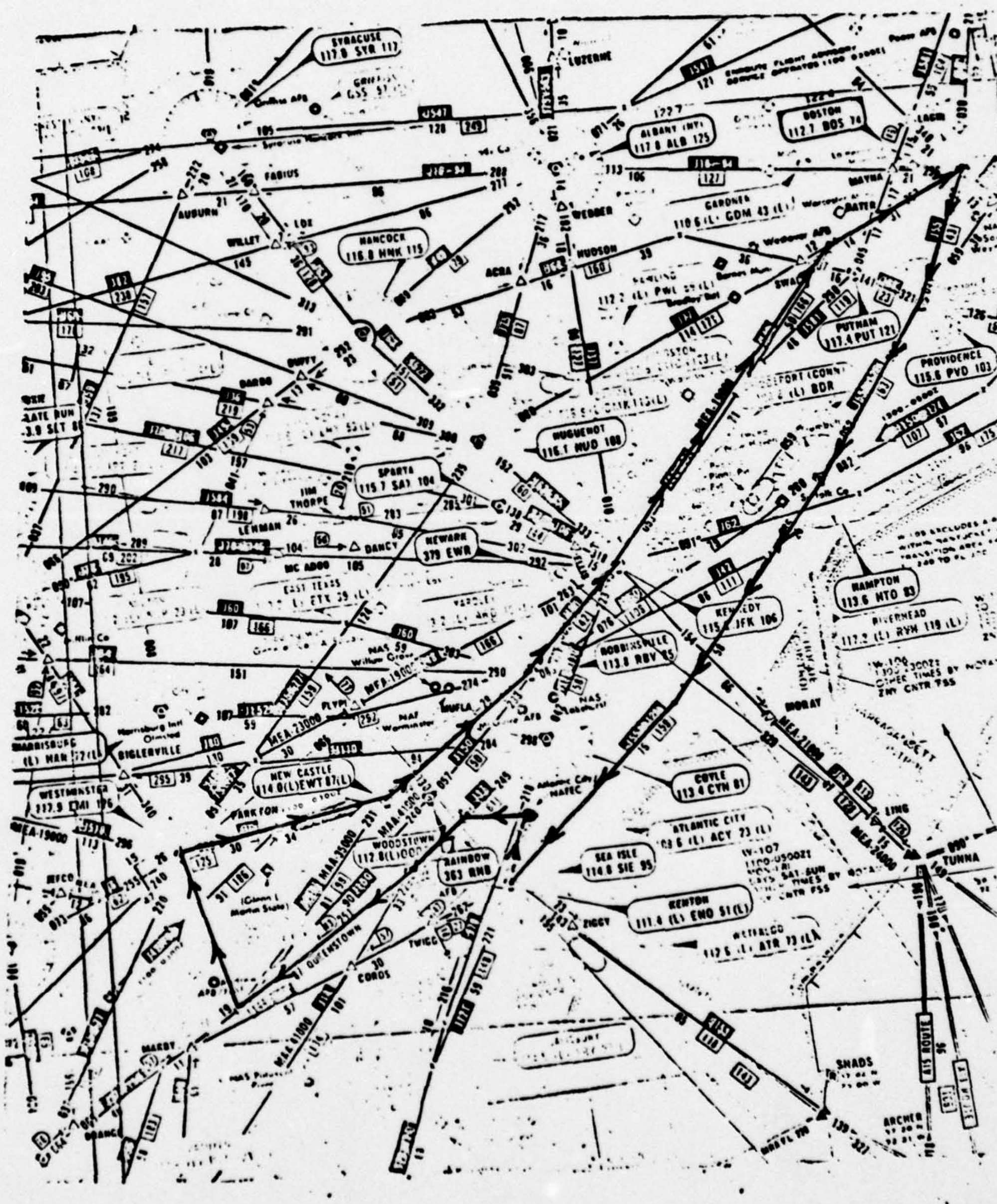


FIGURE B-11. PATTERN #15

APPENDIX C

THREAT LOGIC *

1. INTRODUCTION

This section describes the threat declaration and evasion logic implemented in the experimental BCAS system. One of the ground-rules for the development of this test system was that the threat logic used must approximate as closely as possible ANTC-117, the threat logic developed for range/range rate CAS systems. The threat declaration and evasion logic described attempts to do just that, and therefore retains some of the limitations of ANTC-117.

2. DATA AVAILABLE TO THREAT LOGIC

The data available to the threat logic with respect to each Global Track includes the following items:

1. TOA History - The last three TOA values measured with respect to the interrogations from each radar included in the Global Track and the time of each measurement.
2. DAZ History - The last three Differential Azimuth values measured with respect to each radar included in the Global Track and the time of each.
3. Active Range History - The last three range measurements obtained by active interrogations (if any) by own aircraft and the time of each.
4. Altitude - The current extrapolated altitude (and altitude rate) of the track.
5. Identity - The Mode-A code associated with the Global Track.

3. CLASSIFICATION OF INTRUDERS

3.1 RANGE, TOA AND DAZ CLASSIFICATION

ANTC-117 used three criteria to evaluate the measured range and range-rate data and to classify the intruder into "Tau" catagories. These are:

---
*B. Hulland, Litchford Electronics.

1. If the measured range is less than 0.5 nmi., a "Tau 1" condition is declared.

2. If -(range - 0.25 nmi.)/(range-rate) is less than 25 seconds, a "Tau 1" condition is declared.

3. If -(range - 1.8 nmi.)/(range-rate) is less than 40 seconds, a "Tau 2" condition is declared.

4. If none of the above is true, no "Tau" condition is declared and the intruder is not further processed.

A similar classification is done by the experimental BCAS system. However, three "Tau" catagories are defined, and the logic to classify a track is more complex. In this classification the active range measurements (if any) are processed exactly like TOA measurements from an additional radar. Since the various measurements are made at different times, they are extrapolated linearly to the current time using the last two measured values in each case. The criteria used for each intruder are:

1. If all the TOA values are less than 6.1 μs (microseconds), a "Tau 0" condition is declared.

2. For each radar, two values are computed (only the first for active interrogations):

   1) -(TOA-3.0 us) (Dif Time)/(Dif TOA)

   2) -(DAZ) (Dif Time)/(Dif DAZ-[0.7 deg][Sign of DAZ])

   where "Dif" means the change in the specified value between the last two measurements (i.e., Dif Time is the time between measurements). If all of these values are less that 25 seconds, a "Tau 1" condition is declared.

3. For each radar, the following value is computed:

   -(TOA-22.0 us)(Dif Time)/(Dif TOA)

   If all of these values are less than 40 seconds, a "Tau 2" condition is declared.

4. If none of the above is true, no "Tau" condition is declared and the intruder is not further processed except in deciding whether to interrogate actively.

It should be noted that in all subsequent processing, a "Tau 0" condition is treated exactly the same as a "Tau 1" condition; the distinction is made here only for convenience in programming.

If an intruder is being tracked only via active interrogations, this classification is exactly equivalent to that of ANTC-117 except that the range rate is obtained by subtraction of successive range measurements rather than from a Doppler measurement.

3.2 ALTITUDE CLASSIFICATION

ANTC-117 further classifies intruders in terms of their altitude relative to own altitude, and in terms of own altitude and altitude rate. The experimental BCAS system classifies them in exactly the same way as ANTC-117 in this respect. (This means that it ignores the intruder's altitude rate, even though that data is readily available in the experimental BCAS.) This classification is as follows:

1. If the difference between the intruder's altitude and own altitude is greater than 3300 ft., the intruder is not further considered by the threat logic.
2. If the difference between the intruder's altitude and own altitude is less than 900 ft. (700 ft. if own altitude is less than 10,000 ft.), the intruder is classified as "Coaltitude".
3. If adding the change in own altitude in the last 30 seconds (or less) to current own altitude would make the intruder "Coaltitude", the intruder is classified as "Predicted Coaltitude".
4. If the intruder is not "Coaltitude", it is classified in terms of the difference between its altitude and own altitude as: "<1400 ft" if the difference is less than 1400 ft., "<1900 ft" if it is less than 1900 ft. or "<3400 ft" otherwise.

4. TIE BREAKING

The one other piece of information needed by the evasion logic is whether the intruder is "Above" or "Below" own. In most cases this presents no problem. However, if an intruder classified as Tau 0, 1 or 2 is reporting its altitude exactly equal to own altitude, a decision must be made whether to consider it as above or below; and if that intruder is also equipped with a BCAS, the decision must be coordinated with it so that both aircraft will not climb (or both dive). This process is known as tie-breaking.

To make possible the required coordination, the experimental BCAS adds pulses to its own Mode-C replies to all interrogations whenever it detects one or more Tau 0, 1 or 2 intruders within 3300 ft. or its own altitude. It does this as follows:

1. If the two most threatening intruders are actually (or are considered to be due to tie-breaking) ABOVE own or if the BCAS is giving a DIVE command, the "X Pulse" will be transmitted.
2. If the two most threatening intruders are actually (or are considered to be due to tie-breaking) BELOW own or if the BCAS is giving a CLIMB command, the "X Pulse" and the "D1 Pulse" will be transmitted.
3. If neither of the above is true, the "D1 Pulse" only will be transmitted as an indication that the BCAS has detected a potential threat, but has not yet decided on a maneuver direction.

These three conditions will be referred to as transmitting DOWN, UP and WARN respectively.

The tie-breaker logic used in the flight test system is the following:

1. If the intruder at own altitude is not transmitting UP or DOWN and own is currently transmitting UP, consider the intruder as BELOW own.

2. If the intruder at own altitude is not transmitting UP or DOWN and own is currently transmitting DOWN, consider the intruder as ABOVE own.
3. If the intruder at own altitude is transmitting UP and own is not currently transmitting UP, consider the intruder as ABOVE own.
4. If the intruder at own altitude is transmitting DOWN and own is not currently transmitting DOWN, consider the intruder as BELOW own.
5. If the Identity of the intruder at own altitude (Mode-A code) is numerically less than own's Identity, consider the intruder as BELOW own.
6. If the Identity of the intruder at own altitude (Mode-A code) is numerically greater than own's Identity, consider the intruder as ABOVE own.
7. If none of the above rules yield a decision, make a 50-50 random choice whether to consider the intruder at own altitude as ABOVE or BELOW. The present program makes that choice by computing the parity of the word "ZMSHT" which is incremented every 9.5 ms.

Note that no provision is made in this program to handle the case where more than one intruder is at own altitude. In this case, all but one (generally the most threatening one) of the intruders at own altitude are treated as though they were ABOVE own, and the one is treated as described above.

5. EVASION LOGIC

The experimental BCAS, like ANTC-117, provided a matrix of responses to all possible combinations of threats from one or two intruders. The matrix used by this program is essentially identical to ANTC-117. In case there are more than two intruders, the two most threatening are selected, and all others are ignored. The following pages are a listing of the response matrix.

NOTE: "LVS" stands for "Limit Vertical Speed to the values below". "N/A means an impossible condition. (See Figures C-1, 2, and 3).

6. *INTERROGATION CONTROL*

The final function performed by the threat logic in the experimental BCAS is to control whether or not active interrogations are transmitted. The only portion of this function that need be commented on here is the "Interrogate on Threat" decision. When this mode is selected and interrogations are not required by the lack of sufficient radars, all intruders within 3300 ft. of own altitude are examined to see if they will be either Tau 0, Tau 1 or Tau 2 (ignoring any data from active interrogation) within the next 10 seconds. If so, active interrogation is selected. (The exclusion of data resulting from active interrogations is to prevent an unstable condition that would occur if an intruder was classified as Tau 2 with the interrogator off, but no threat with the interrogator on.)

All Intruders Above:

Intruder 2	Coaltitude Tau 0 or 1	Coaltitude Tau 2	Predicted Coaltitude <1400 ft Tau 0,1,2	<1400 ft Tau 0,1,2	Predicted Coaltitude <1900 ft Tau 0,1,2	1900 ft Tau 0,1,2	Predicted Coaltitude <3400 ft Tau 0,1,2	<3400 ft Tau 0,1,2
<3400 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	LVS 500fpm Up	Level Off Do Not Turn LVS 1000fpm Up	LVS 1000fpm Up	Level Off Do Not Turn LVS 2000fpm Up	LVS 2000fpm Up
Predicted Coaltitude <3400 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	N/A	Level Off Do Not Turn LVS 1000fpm Up	N/A	Level Off Do Not Turn LVS 2000fpm Up	Level Off Do Not Turn LVS 2000fpm Up
<1900 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	LVS 500fpm Up	Level Off Do Not Turn LVS 1000fpm Up	LVS 1000fpm Up	N/A	LVS 1000fpm Up
Predicted Coaltitude <1900 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	N/A	Level Off Do Not Turn LVS 1000fpm Up	Level Off Do Not Turn LVS 1000fpm Up	Level Off Do Not Turn LVS 1000fpm Up	Level Off Do Not Turn LVS 1000fpm Up
<1400 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	LVS 500fpm Up	N/A	LVS 500fpm Up	N/A	LVS 500fpm Up
Predicted Coaltitude <1400 ft	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 500fpm Up	Level Off Do Not Turn LVS 500fpm Up
Coaltitude Tau 2	Dive Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 200fpm Up	Do Not Turn LVS 200fpm Up
Coaltitude Tau 0 or 1	Dive Do Not Turn LVS 200fpm Up	Dive Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	Dive Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	Dive Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	Dive Do Not Turn LVS 200fpm Up
None	Dive Do Not Turn	Do Not Turn LVS 200fpm Up	Level Off Do Not Turn LVS 500fpm Up	LVS 500fpm Up	Level Off Do Not Turn LVS 1000fpm Up	LVS 1000fpm Up	Level Off Do Not Turn LVS 2000fpm Up	LVS 2000fpm Up

Intruder 1 ==>

FIGURE C-1. THREAT LOGIC - ALL INTRUDERS ABOVE

One Intruder Above and One Below:

Intruder Below / Intruder Above ==>	Coaltitude Tau 0 or 1	Coaltitude Tau 2	Predicted Coaltitude <1400 ft Tau 0,1,2	<1400 ft Tau 0,1,2	Predicted Coaltitude <1900 ft Tau 0,1,2	<1900 ft Tau 0,1,2	Predicted Coaltitude <3400 ft Tau 0,1,2	<3400 ft Tau 0,1,2
<3400 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up 2000fpm Dn	Do Not Turn LVS 200fpm Up 2000fpm Dn	Level Off Do Not Turn LVS 500fpm Up 2000fpm Dn	LVS 500fpm Up 2000fpm Dn	Level Off Do Not Turn LVS 1000fpm Up 2000fpm Dn	LVS 1000fpm Up 2000fpm Dn	Level Off Do Not Turn LVS 2000fpm Up 2000fpm Dn	LVS 2000fpm Up 2000fpm Dn
Predicted Coaltitude <3400 ft Tau 0, 1 or 2	Level Off Do Not Turn Level Off 500fpm Up 2000fpm Dn	Level Off Do Not Turn Level Off 200fpm Up 2000fpm Dn	N/A	Level Off Do Not Turn Level Off 500fpm Up 2000fpm Dn	N/A	Level Off Do Not Turn Level Off 1000fpm Up 2000fpm Dn	N/A	Level Off Do Not Turn Level Off 2000fpm Up 2000fpm Dn
<1900 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up 1000fpm Dn	Do Not Turn LVS 200fpm Up 1000fpm Dn	Level Off Do Not Turn LVS 500fpm Up 1000fpm Dn	LVS 500fpm Up 1000fpm Dn	Level Off Do Not Turn LVS 1000fpm Up 1000fpm Dn	LVS 1000fpm Up 1000fpm Dn	Level Off Do Not Turn LVS 2000fpm Up 1000fpm Dn	LVS 2000fpm Up 1000fpm Dn
Predicted Coaltitude <1900 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Up 1000fpm Dn	Level Off Do Not Turn LVS 200fpm Up 1000fpm Dn	N/A	Level Off Do Not Turn LVS 500fpm Up 1000fpm Dn	N/A	Level Off Do Not Turn LVS 1000fpm Up 1000fpm Dn	N/A	Level Off Do Not Turn LVS 2000fpm Up 1000fpm Dn
<1400 ft Tau 0, 1 or 2	Dive Do Not Turn LVS 200fpm Up 500fpm Dn	Do Not Turn LVS 200fpm Up 500fpm Dn	Level Off Do Not Turn LVS 500fpm Up 500fpm Dn	LVS 500fpm Up 500fpm Dn	Level Off Do Not Turn LVS 1000fpm Up 500fpm Dn	LVS 1000fpm Up 500fpm Dn	Level Off Do Not Turn LVS 2000fpm Up 500fpm Dn	LVS 2000fpm Up 500fpm Dn
Predicted Coaltitude <1400 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Up 500fpm Dn	Level Off Do Not Turn LVS 200fpm Up 500fpm Dn	N/A	Level Off Do Not Turn LVS 500fpm Up 500fpm Dn	N/A	Level Off Do Not Turn LVS 1000fpm Up 500fpm Dn	N/A	Level Off Do Not Turn LVS 2000fpm Up 500fpm Dn
Coaltitude Tau 2	Dive Do Not Turn LVS 200fpm Up 200fpm Dn	Do Not Turn LVS 200fpm Up 200fpm Dn	Level Off Do Not Turn LVS 500fpm Up 200fpm Dn	Do Not Turn LVS 500fpm Up 200fpm Dn	Level Off Do Not Turn LVS 1000fpm Up 200fpm Dn	Do Not Turn LVS 1000fpm Up 200fpm Dn	Level Off Do Not Turn LVS 2000fpm Up 200fpm Dn	Do Not Turn LVS 2000fpm Up 200fpm Dn
Coaltitude Tau 0 or 1	Level Off Do Not Turn LVS 200fpm Up 200fpm Dn	Climb Do Not Turn LVS 200fpm Up 500fpm Dn	Level Off Do Not Turn LVS 500fpm Up 200fpm Dn	Climb Do Not Turn LVS 500fpm Up 500fpm Dn	Level Off Do Not Turn LVS 1000fpm Up 200fpm Dn	Climb Do Not Turn LVS 1000fpm Up 500fpm Dn	Level Off Do Not Turn LVS 2000fpm Up 200fpm Dn	Climb Do Not Turn LVS 2000fpm Up 500fpm Dn

FIGURE C-2. THREAT LOGIC - ONE INTRUDER ABOVE AND ONE BELOW

All Intruders Below:

Intruder 2 \ Intruder 1 →	Coaltitude Tau 0 or 1	Coaltitude Tau 2	Predicted Coaltitude <1400 ft Tau 0,1,2	<1400 ft Tau 0,1,2	Predicted Coaltitude <1900 ft Tau 0,1,2	<1900 ft Tau 0,1,2	Predicted Coaltitude <3400 ft Tau 0,1,2	<3400 ft Tau 0,1,2
<3400 ft Tau 0, 1 or 2	Climb Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	LVS 500fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn	LVS 1000fpm Dn	Level Off Do Not Turn LVS 2000fpm Dn	LVS 2000fpm Dn
Predicted Coaltitude <3400 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	N/A	Level Off Do Not Turn LVS 1000fpm Dn	N/A	Level Off Do Not Turn LVS 2000fpm Dn	Level Off Do Not Turn LVS 2000fpm Dn
<1900 ft Tau 0, 1 or 2	Climb Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	LVS 500fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn	LVS 1000fpm Dn	N/A	LVS 1000fpm Dn
Predicted Coaltitude <1900 ft Tau 0, 1 or 2	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	N/A	Level Off Do Not Turn LVS 1000fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn
<1400 ft Tau 0, 1 or 2	Climb Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	LVS 500fpm Dn	N/A	LVS 500fpm Dn	N/A	LVS 500fpm Dn
Predicted Coaltitude <1400 ft	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Level Off Do Not Turn LVS 500fpm Dn
Coaltitude Tau 2	Climb Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 200fpm Dn	Do Not Turn LVS 200fpm Dn
Coaltitude Tau 0 or 1	Climb Do Not Turn LVS 200fpm Dn	Climb Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Climb Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Climb Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	Climb Do Not Turn LVS 200fpm Dn
None	Climb Do Not Turn	Do Not Turn LVS 200fpm Dn	Level Off Do Not Turn LVS 500fpm Dn	LVS 500fpm Dn	Level Off Do Not Turn LVS 1000fpm Dn	LVS 1000fpm Dn	Level Off Do Not Turn LVS 2000fpm Dn	LVS 2000fpm Dn

FIGURE C-3. THREAT LOGIC - ALL INTRUDERS BELOW

APPENDIX D
RANGE-BEARING COMPUTATIONS

D.1 INTRODUCTION

The range and bearing to a threat aircraft are not currently computed by the BCAS system in flight. Instead sufficient data are recorded to allow after-the-fact computation, based on the measurements made in flight.

A routine to carry out the range and bearing calculations had been developed in the course of work preceding the current contract, and had been used to track aircraft observed by the demonstration BCAS system placed on ten of the Pan Am buildings. In the configuration of radars and aircraft encountered there, it had operated satisfactorily. The routine was made available by Megadata.

At TSC a simulation program was written to test the accuracy of the solutions and the degree to which they were affected by errors in the measurements on which the calculations were based.

Test runs showed that the PASIVE subroutine contained errors. In trying to find the causes of these errors, the documentation supplied with PASIVE was not helpful. Much of it was unrelated to the actual program, and the algorithms described themselves were incorrect.

Two things were clear fairly early:

1. that the problem was rather complicated, due largely to numerical instability in directions near the radars
2. that, when PASIVE was written, the difficulties were not recognized.

PASIVE consisted of three parts:

1. a selection of two radars to use for initialization
2. initialization
3. iteration using a hill-climbing technique.

Analysis and/or test runs showed that each of these three parts was flawed. Consequently, it was necessary to write a new subroutine, NUPAS. NUPAS is called by the same sequence that calls PASIVE, so that any programs written to call PASIVE need only be changed to accommodate the different function name.

Radar Selection

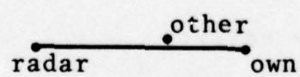
PASIVE selects, for its initialization procedure, the radar with the largest TOA and the radar with the smallest TOA. Presumably the reason it does this is to get radars whose difference in bearing from own is large enough. The problem is that the most significant factor for inducing initialization error is the smallness of the smaller TOA. Thus, in an environment where there are many radars to choose amongst, PASIVE's selection almost maximizes the initialization error. (The reason for this will be discussed in b). The problem becomes even more serious when garble is considered.

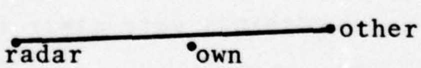
The NUPAS code employs different radar selection criteria.

There are two cases:

i) Suppose that there are radar pairs whose bearing difference is between 20 and 160 degrees.

There are, with respect to a given radar, two bad geometries as sketched below:

a) 

b) 

In a), other is almost between own and the radar. In b) other is almost opposite the radar from own. (The reasons that these configurations are "bad" are discussed in what follows)

a) is worse than b) in the sense that in a) there is a larger set such that, if other is in that set, there will be a poor range bearing solution than there is in b). The radar pair should, then, be chosen in such a way as to avoid both a) and b) with greater

care taken to avoid a).

a) occurs when both the TOA and differential azimuth measurements are small, b) when just the differential azimuth is small.

The new radar selection algorithm chooses the radar pair (with good seperation) whose minimum product of TOA with absolute value of differential azimuth is largest. Thus, a) and b) are both avoided with larger berth given to a).

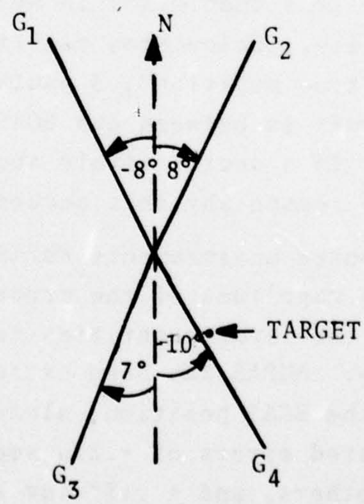
ii) if there is no radar pair with a spread as in i), the pair that most nearly meets this requirement is selected.

The following are the reasons why this procedure should be temporary:

1. The values of 20° and 160° are only estimates based on a limited number of simulations.

2. More important, the numerical difficulties of NUPAS were the only considerations when the angles 20° and 160° were estimated. No consideration was given to garble.

3. In the figure



there are no 'good' radar spreads, so that the selection algorithm chooses the best spread, i.e., the radar pair G_2, G_4. This is unfortunate because the TOA measured from G_4 is very small. Also,

there will be garble in this configuration. Here the best choice of radar pairs is probably G_1, G_3. What follows is a discussion of the remaining parts of NUPAS, which may be considered to be in final form except for program implementation details, a comparison with the original Megadata-supplied range-bearing calculations program PASIVE; and a discussion of the problems inherent in the task.

D.2 SIMULATED INPUTS

NUPAS has been tested with simulated inputs. This means that some configuration of radars and aircraft is assumed and the azimuth, differential azimuth, and TOA measurements that the BCAS-equipped aircraft would make are calculated. Some known "error" can then be added to the computed values to simulate measurement noise. The simulated measurements are used as inputs to NUPAS, and the range and bearing to the threat aircraft from the BCAS aircraft, as well as the ranges to the ground radars, are calculated. The calculated results are compared and with the configuration initially assumed to determine the error in the NUPAS results.

With error-free measurements NUPAS produces essentially perfect results (errors in range to the threat of less than a foot and bearing errors of less than 0.1°) in most configurations. NUPAS tends to fail (i.e., calculates positions for the threat some 1000' from the "true position", 3 nautical miles from own) when the threat aircraft is between the BCAS aircraft and one of the locked radars, or in a sector within about 20° of the radar, viewed from own. The reason why this occurs is described below.

With error-corrupted measurements NUPAS still produces good results. The precise magnitude of the error in the computed position due to error in the input quantities is a function of the geometry in each case. NUPAS has been exercised using three simulated radars about the BCAS position, always selecting two for calculations. Simulated errors of $\pm .27\mu$ sec for TOA, $\pm$ 75 ft for altitude of own and others, and $\pm$ .15° for azimuth and differential azimuth were introduced in various combinations.

In the simulations, these errors were introduced as fixed quantities added to the values that the "measurements" should have in the assumed geometry. The magnitude of the "errors" corresponds roughly to the RMS errors (i.e., the σ) of the measurements made by the BCAS system.

No combination of these errors resulted in computed bearing errors of more than two degrees in any geometry tested. The range error was significantly affected only by errors in the TOA measurements. The other errors resulted in computed range errors of some tens of feet. The TOA errors results in range errors of generally less than 200 feet. A small set of geometric configurations resulted in range errors of about 500 feet. It is believed that these errors can be attributed to a bad selection of radars.

All calculations were completed in two or three iterations.

D.3 FLIGHT TEST DATA INPUTS

A set of programs have been written to extract target reports from the BCAS magnetic tapes and construct disk files, sorted by intruder transponder codes. These files serve as inputs to a program using NUPAS to construct intruder trajectories, i.e., plots of range and bearing to the target as a function of time. These plots, given ARTS separation data for comparison, are presented elsewhere in this report.

I. The Nature of the Problem and an Overview of the Solutions

Let $n \geq 2$.

Given n radars $G_1, \text{---}, G_n$ (assumed to be at sea level) let (for $1 \leq i \leq n$)

β_i = the bearing of G_i from own

α_i = the differential azimuth, with respect to G_i, from own to other

T_i = the time of arrival (or delayed time of arrival or TOA) with respect to G_i.

Furthermore let

r = the horizontal distance from own to other

θ = the bearing of other with respect to own

H = the altitude of other

H_o = the altitude of own.

Given β_i, α_i, T_i, H and H_o, the problem is to compute r and θ.

It is not difficult to find a function F such that, for each i, $T_i = F(r,\theta,\alpha_i,\beta,H_o)$. Thus the problem reduces to solving this system of n equations for the two unknowns r and θ.

Unfortunately the function F is complicated; so if the system has a closed form solution, it is not easy to find. It seems, then, to be necessary to resort to numerical methods.

The notation and choice of variables used here is different from that of PASIVE because PASIVE uses rectangular coordinates. PASIVE's notation will be translated to cylindrical coordinates here in order to simplify this exposition:

a) <u>The Method of PASIVE</u>

First a function f is defined such that, for small values of α_i and values of H and H_o that are not too large, $f(r,\theta,\beta_i,H,H_o)$ is a decent approximation to $F(r,\theta,\alpha_i,\beta_i,H,H_o)$. In physical terms, $f(r,\theta,\beta_i,H,H_o)$ is the expression for the TOA in a geometric situation in which the radar is at an infinite distance. Then the locus of intruder position leading to a constant observed TOA is a paraboloid of revolution, not an ellipsoid of revolution. Then two radars G_μ and G_ν are chosen and the system of equations

$$T_\mu = f(r,\theta,\beta_\mu,H,H_o)$$

$$T_\nu = f(r,\theta,\beta_\nu,H,H_o)$$

is solved, in closed form, for $r = r_o$, $\theta = \theta_o$.

Let $G(r,\theta) = \sum_{i=1}^{n} \left(F(r,\theta,\alpha_i,\beta_i,H,H_o) - T_i\right)^2$. If $(\bar{r},\bar{\theta})$ solves

the system

$$F(r,\theta,\alpha_i,\beta_i,H,H_o) = T_i \qquad 1 \leq i \leq n$$

then $G(\overline{r},\overline{\theta}) = 0$. This suggests that the system may be solved by minimizing G.

Let $\theta(x,y)$ be such that $\sqrt{x^2+y^2}\cos\theta(x,y) = x$ and $\sqrt{x^2+y^2}$ $\sin\theta(x) = y$ ($\theta(x,y)$ is well-defined modulo 2π) and define $u(x,y) = G(\sqrt{x^2+y^2},\ \theta(x,y))$. u is just the rectangular coordinate version of G.

If u achieves a minimum at $(\overline{x},\overline{y})$ then $\frac{\partial u}{\partial x}(\overline{x},\overline{y}) = \frac{\partial u}{\partial y}(\overline{x},\overline{y}) = 0$.

$$\text{Let } v(x,y) = \left(\frac{\partial u}{\partial x}(x,y)\right)^2 + \left(\frac{\partial u}{\partial y}(x,y)\right)^2 .$$

PASIVE proceeds to compute $(\overline{x},\overline{y})$ by solving $v(x,y) = 0$.

Let $\nabla v(x,y)$ denote the gradient of v at (x,y). Suppose that, after the $i^{\underline{th}}$ iteration, the approximate solution to $v(x,y) = 0$ is (x_i,y_i). PASIVE computes a vector $\vec{w}_i$ that is presumably an approximation to the appropriate Newton-Raphson multiple of $\nabla v(x_i,y_i)$ and obtains $(x_{i+1},y_{i+1}) = (x_i,y_i) + \vec{w}_i$. The iterations continue until either $i = 20$ or $\vec{w}_i$ is sufficiently small.

b) <u>The Method of NUPAS</u>

As in PASIVE, two radars G_μ and G_ν are selected (but differently) for initialization. Assume, for simplicity, that $\mu = 1$ and $\nu = 2$.

The NUPAS initialization occurs in two stages. i) The same function f chosen by PASIVE is used by NUPAS and the resulting system of two equations in two unknowns is solved for $r_o = \tilde{r}_o, \theta_o = \tilde{\theta}_o$. ii) The values r_o,θ_o are used to estimate $F(r,\theta,\alpha_i,\beta_i,H,H_o) - f(r,\theta,\beta_i,H,H_o)$ for $i = 1,2$. This 'error' is then absorbed by the given parameters T_i which leads to a system of equations

$$\tilde{T}_i = f(r,\theta,\beta_i,H,H_o) \qquad i = 1,2$$

which is then solved for $r = r_o$, $\theta = \theta_o$. The iteration will begin here.

In the iteration, NUPAS uses only the two radars G_1 and G_2 in order to avoid certain complications.

Let $M(r,\theta)$ denote the 2 x 2 matrix

$$\begin{pmatrix} \frac{\partial F}{\partial r}(r,\theta,\alpha_1,\beta_1,H,H_o) & \frac{\partial F}{\partial \theta}(r,\theta,\alpha_1,\beta_1,H,H_o) \\ \frac{\partial F}{\partial r}(r,\theta,\alpha_2,\beta_2,H,H_o) & \frac{\partial F}{\partial \theta}(r,\theta,\alpha_2,\beta_2,H,H_o) \end{pmatrix}$$

If, after the $i^{\underline{th}}$ iterative step, the approximate solution is (r_i,θ_i), (r_{i+1},θ_{i+1}) is defined by the matrix equation

$$\begin{pmatrix} r_{i+1} \\ \theta_{i+1} \end{pmatrix} = \begin{pmatrix} r_i \\ \theta_i \end{pmatrix} + M(r,\theta)^{-1} \begin{pmatrix} T_1 - F(r_i,\theta_i,\alpha_1,\beta_1,H,H_o) \\ T_2 - F(r_i,\theta_i,\alpha_2,\beta_2,H,H_o) \end{pmatrix}$$

Originally, the iteration was stopped if

i) $i = 20$

ii) $r_{i+1} - r_i$ and $\theta_{i+1} - \theta_i$ were both sufficiently small or

iii) $\big(F(r_{i+1},\theta_{i+1},\alpha_1,\beta_1,H,H_o),\ F(r_{i+1},\theta_{i+1},\alpha_2,\beta_2,H,H_o)\big)$ was further from (T_1,T_2) than $\big(F(r_i,\theta_i,\alpha_1,\beta_1,H,H_o),\ F(r_i,\theta_i,\alpha_2,\beta_2,H,H_o)\big)$ is.

The new criterion is based on the following observations: The iteration is along a vector field.

If (r,θ) is the solution to the system of equations then (r,θ) is, of course, a sink of this field, but it is not the only sink. In particular $(-r,\theta)$, (which is geometrically meaningless) and $(r,\pi+\theta)$ are both sinks. If either of these two additional sinks is chosen by the iteration, the computed position of other will be the reflection about own of the true position.

Fortunately it is not difficult to tell, from the input data, if this reflection has been computed. Then the program can correct the 'mistake' of iterating the wrong sink. This eliminates one of the reasons for checking the results after each iterative step and then deciding whether or not to continue.

The new algorithm stops iterating when either 20 iterations have been made or when the previous iteration effected a very small correction. The change has resulted in fewer but wilder wild points.

II. The Need for Changing PASIVE and the Limitations of NUPAS

a. Radar Selection

PASIVE selects, for its initialization procedure, the radar with the largest TOA and the radar with the smallest TOA. Presumably the reason it does this is to get radars whose difference in bearing from own is large enough. The problem is that the most significant factor for inducing initialization error is the smallness of the smaller TOA. Thus, in an environment where there are many radars to choose amongst, PASIVE's selection almost maximizes the initialization error. (The reason for this will be discussed in b).) The problem becomes even more serious when garble is considered.

An algorithm that avoids this problem has been developed and incorporated in NUPAS. As discussed above, this algorithm too must be considered preliminary in that it does not consider all aspects of the BCAS system.

b. Initialization

Let $R(r,\theta,\alpha,\beta) = \frac{r}{\sin\alpha}\sin(\alpha+\beta-\theta)$ and, for $i = 1,2$, let $\overline{R}_i = R(r,\theta,\alpha_i,\beta_i)$. The law of sines shows that $\overline{R}_i$ is the horizontal distance from own to the radar G_i.

The law of cosines and some algebraic manipulation show that

$$T_i = \frac{r^2 - 2rR_i\cos(\theta-\beta_i) + H^2 - H_o^2}{\sqrt{\overline{R}_i^2 + r^2 - 2\overline{R}_i r\cos(\theta-\beta_i) + H^2} + \sqrt{\overline{R}_i^2 + H_o^2} + \sqrt{r^2 + (H-H_o)^2}}$$

Then

$$F(r,\theta,\alpha_i,\beta_i,H,H_o) =$$

$$\frac{r^2-2rR_i(r,\theta,\alpha_i,\beta_i)\cos(\theta-\beta_i)+H^2-H_o^2}{\sqrt{R_i(r,\theta,\alpha_i,\beta_i)^2+r^2-2R_i(r,\theta,\alpha_i,\beta_i)r\cos(\theta-\beta_i)+H^2}+\sqrt{R_i(r,\theta,\alpha_i,\beta_i)^2+H_o^2}}$$

$$+\sqrt{r^2+(H-H_o)^2}$$

If it is assumed that $\bar{R}_i >> r,H,H_o$ then the denominator of the first term of F is close to $2\bar{R}_i$ and the definition $f(r,\theta,\beta,H,H_o) = -r\cos(\theta-\beta) + \sqrt{r^2+(H-H_o)^2}$ (recall $f(r,\theta,\beta_i,H,H_o)$ is supposed to be an approximation to $F(r,\theta,\alpha_i,\beta_i,H,H_o)$) becomes obvious. Note that this approximation becomes weaker as the ratio $\frac{r^2+H^2-H_o^2}{2R_i}$ becomes larger.

Let $A = 1 - \cos(\beta_2-\beta_1)$

$$V = \frac{1}{A^2}\left((T_1+T_2)^2 + (4-2A)T_1T_2-2A(H-H_o)^2\right) \text{ and}$$

$$W = \frac{2(T_1+T_2)}{A^2}\sqrt{(4-2A)T_1T_2+(A^2-2A)(H-H_o)^2}\ .$$

The system of simultaneous equations

$$T_i = f(r,\theta,\beta_i,H,H_o) \qquad i = 1,2$$

has two solutions, (r,θ). The two values of r are given by $\sqrt{V+W}$

PASIVE made an algebraic mistake which NUPAS corrects.

To arrive at r it is now necessary to choose between $\sqrt{V+W}$ and $\sqrt{V-W}$. PASIVE produced wild points in good geometric configurations because it did not always make this choice correctly. NUPAS has a different algorithm for making the choice.

Once r is known it is not difficult to solve for θ.

It was mentioned earlier that the approximation $F(r,\theta,\alpha_i,\beta_i,H,H_o) \simeq f(r,\theta,\beta_i,H,H_o)$ becomes weaker as

$$\frac{r^2 + H^2 - H_o^2}{2\overline{R}_i}$$

becomes larger. This observation is important because

1. if H and H_o are large, $H^2-H_o^2$ can be significant even if $H-H_o$ is small.
2. for reasons that will be gone into shortly and in c) it is important to have a good initialization if one of the TOAs is small.

NUPAS uses the (r,θ) computed above to compute numbers $\tilde{T}_i$ in such a way that the correct solution of the system $\tilde{T}_i = f(r,\theta,\beta_i, H,H_o)$ will be a better initialization than the one previously computed.

The following is one reason why special care is needed when θ is close to one of the β_i's, i.e., when the intruder is approximately in the direction of one of the radars when viewed from the BCAS aircraft.

It is true that the approximations $F(r,\theta,\alpha_i,\beta_i,H,H_o) \approx f(r,\theta,\beta_i,H,H_o)$ are fairly good. However it does not necessarily follow from this that the solution of $T_i = F(r,\theta,\alpha_i,\beta_i,H,H_o)$ i=i,2 is necessarily close to a solution of $T_i = f(r,\theta,\beta_i,H,H_o)$ i=i,2. It would follow if the determinant of the derivative matrix

$$\begin{bmatrix} \frac{\partial f}{\partial r}(r,\theta,\beta_1,H,H_o) & \frac{\partial f}{\partial \theta}(r,\theta,\beta_1,H,H_o) \\ \frac{\partial f}{\partial r}(r,\theta,\beta_2,H,H_o) & \frac{\partial f}{\partial \theta}(r,\theta,\beta_2,H,H_o) \end{bmatrix}$$

were not too small.

But this determinant will be 0 when

$$\sqrt{r^2+(H,H_o)^2}\cos\left(\frac{\beta_2-\beta_1}{2}\right) = r\cos\left(\theta - \frac{\beta_1+\beta_2}{2}\right).$$

If $H = H_o$ this occurs when $\theta = \beta_1$ and when $\theta = \beta_2$.

This is one of the reasons that NUPAS (and PASIVE) had difficulties when the bearing of other is close to the bearing of one of the radars. Note also that, when $|H-H_o|$ becomes larger, the center of the numerically unstable ranges moves a bit from the directions of the radars.

c. Iteration:

i) PASIVE

See I,a) for notation.

It was mentioned there that PASIVE does not iterate along ∇v but rather (at the m^{th} iterative step) along a vector $\vec{w}_m$.

Suppose that, at the m^{th} iterative step, (r_m, θ_m) is the approximation to the solution. For $1 \leq i \leq n$,

$$S_i^m = \frac{r_m}{\sin\alpha_i} \sin(\alpha_i + \beta_i - \theta_m)$$

is an approximation to $\overline{R}_i$, the horizontal distance to the i^{th} radar.

PASIVE obtains the vector $\vec{w}_i$ by computing ∇v under the assumption that S_i^m is constant in r and θ and then updating S_i^m to S_i^{m+1} after the iteration, provided $|\alpha_i| \geq .05$.

There are two problems here:

1. the assumption introduces non-trivial error.
2. if $\overline{R}_i$ is large compared to r, then α_i, will be small for a sizable range of values of θ so there will be no updating of S_i^m.

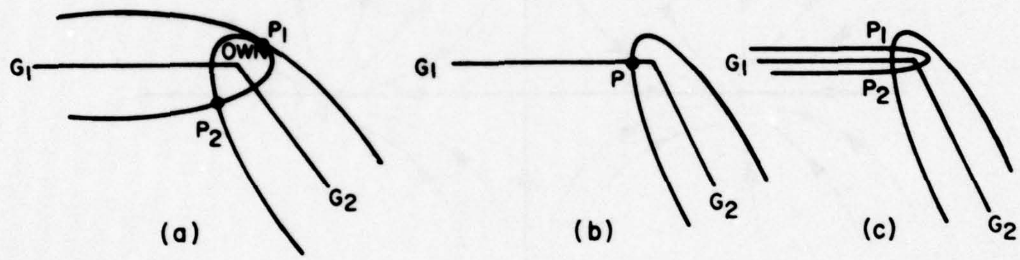
The combination of these two problems produces significant error even in good geometric configurations. Suppose there are two radars G_1 and G_2. For i=1,2, let $\vec{R}_i$ be the horizontal projection of the vector from own to G_i. Let $\vec{S}$ be the horizontal projection of the vector from own to other. The error is especially significant (as shown by test runs) when $\vec{S}$ is a convex linear combination of $\vec{R}_1$ and $\vec{R}_2$, i.e., when the projection of other is in the

smaller wedge determined by own and the two radars.

There is yet another problem which is very serious in an environment where there are only two radars (so it may not be possible to choose a good geometric configuration).

When the distances from own to the radars are known or approximated and the heights of the aircraft are known, then knowledge of each TOA restricts the position of other to a horizontal ellipse whose major axis is in the vertical plane of the line segment joining own to the radar.

Consider the following sketches:



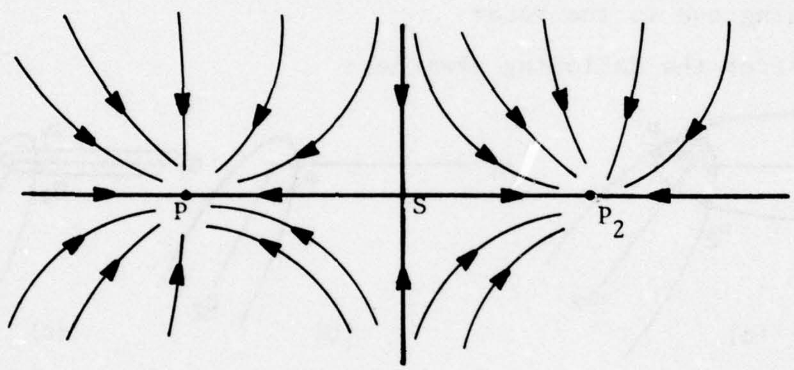
In figures a) and c), P_1 and P_2 represent the two possible positions of other. In figure b) other has a TOA of 0 with respect to G_1. In c) this TOA is small.

In case c) (or, for the matter a)) after successive iteration the approximating solutions will become close to either P_1 or P_2. If the discrete nature of the iteration is ignored, the initialization will probably move to either P_1 or P_2 the two sinks of the flow (or peaks of hills or bottoms of valleys or ω-points of the differential equation, all of which mean the same thing) with the choice depending on whether the initialization is in the sphere of influence (stable manifold) of P_1 or P_2. In the range of small TOA's P_1 and P_2 are not very far apart so a small initialization error can result in the selection of the wrong sink.

The problem is further complicated by the fact that the iteration is discrete. An overeager iterative step can take a point out of the right sphere of influence and into the wrong one.

The result of all this is that if other is too nearly in line with one of the radars, the initialization error might actually be doubled by the iteration.

As a final randomizer, successive iterations may take the point close to the 'saddle' S, between the two sinks.



The vector is 0 at S and small near S, and the next iteration will stop near the saddle.

This problem makes it very important that the initialization be good, expecially if the bearing of other is close to the bearing of one of the radars. As mentioned earlier, this is precisely the configuration in which the initialization is weakest.

In summary, there is going to be a bad region such that, if other is in that region, the iteration may not improve the initialization. Furthermore this bad region is where the initialization is weakest.

ii) <u>NUPAS</u>

The essence of the method is described in Ib. At the present time there is one known difficulty in the procedure and one possible difficulty.

Let for j = 1,2

$$S_j = \text{sign } (\sin\alpha_j)$$

$$U_{1,j} = U_1(r,\theta,\alpha_j,\beta_j,H,H_o) = - r^2 \sin\left(\alpha_j + 2(\beta_j - \theta)\right)$$

$$+ (H^2 - H_o^2) \sin\alpha_j$$

$$U_{2,j} = U_2(r,\theta,\alpha_j,\beta_j,H,H_o) = \sin\alpha_j U_1 + r^2 \left(\frac{1-\cos 2(\alpha_j+\beta_j-\theta)}{2}\right)$$

$$+ H_o^2 \sin^2\alpha_j$$

$$U_{3,j} = U_3(r,\theta,\alpha_j,\beta_j,H,H_o) = r^2 \left(\frac{1-\cos 2(\alpha_j+\beta_j-\theta)}{2}\right)$$

$$+ H_o^2 \sin^2\alpha_j .$$

Let

$$U_4 = U_4 \; (r,H,H_o) = r^2 + (H-H_o)^2$$

For each j, $F(r,\theta,\alpha_j,\beta_j,H,H_o) = \dfrac{S_j U_{1,j}}{\sqrt{U_{2,j}} + \sqrt{U_{3,j}}} + \sqrt{U_4}$

If $\alpha_j = 0$, $H = H_o$, and $\theta = \beta_j$ or $\theta = \beta_j + \pi$ then $U_{1,j} = U_{2,j} = U_{3,j} = 0$.

The nature of the derivative of F is, then, unclear when other is above the horizontal projection of the line determined by own and one of the radars.

The results of the simulation runs seem to indicate that the problem is serious if the bearing of other is close to that of one of the radars and not as serious (possibly because of accurate initialization) if other is nearly opposite one of the radars.

APPENDIX E

BCAS FLIGHT TEST TAPE FORMAT

1. PURPOSE

1.1 The tape should contain the results of each test.

1.2 It should contain enough information to follow the data reduction carried out during the flight.

1.3 It should contain the appropriate information to do a three dimensional reconstruction of target position if such information is available.

2. CONSTRAINTS

2.1 The data manipulation strictly for tape output must be minimized so as to not create a large overhead.

2.2 The data written to tape should be minimized so as to not burden the DMA and not steal too large a fraction of memory cycles.

2.3 The data must be heavily blocked on tape to minimize program intervention.

3. GENERAL FORMAT

3.1 Each logical record is fixed at eighty characters.

3.2 The characters are coded in ASCII.

3.3 The tape is IBM compatible - 9 track at 800 bpi.

3.4 The physical records consist of ten logical records blocked together. There are no extra block control characters. Thus, a physical record is 800 characters in length.

3.5 A logical record consists of two - 1 character fields followed by thirteen - 6 character fields.

3.5.1 The first two fields are always numeric and serve to identify the record tape.

3.5.2 The remaining fields are usually written in octal format. When a field contains alphabetic information, the previous record always specifies that alphabetic information is coming. Thus, a different format statement may be used.

3.6 Record Types

3.6.1 Type 0-1 Header

3.6.2 Type 0-2 Header (alphabetic info)

3.6.3 Type 1-1 Main Beam Interrupts (unrecognized)

3.6.4 Type 2-1 Recognized and locked radars

3.6.5 Type 2-2 Recognized and locked radars (alphabetic info)

3.6.6 Type 2-3 Recognized and locked radars

3.6.7 Type 3-1 Raw replies

3.6.8 Type 3-2 Raw replies (interrogation table)

3.6.9 Type 3-3 Raw replies (reply data)

3.6.10 Type 4-1 First correlated replies

3.6.11 Type 5-1 Second correlation

3.6.12 Type 6-1 Third correlation

3.6.13 Type 7-1 Threat Info.

3.7 A single file mark is written before the first physical record on the tape. A triple file mark is written after the last physical record on the tape.

4. DETAILED FORMATS

4.1 Type 0-1 Header

4.1.1 Fields 1 and 2 = 0 and 1 respectively.

4.1.2 Always present, occurs at restart and once per minute.

4.1.3 Field 3 and 4 = double word internal clock, LSB = 0.145 μsec, 6 + 6 octal digits from 16 bit machine.

4.1.4 Field 5 = Date; month, day, year, 6 digits format MMDDYY

4.1.5 Field 6 = time, hour, minute; 4 decimal digits right adjusted.

4.1.6 Field 7 = time; seconds; tenth seconds, 3 decimal digits right adjusted.

4.1.7 Field 8 = System version No.*1000(8)+current patch no.

4.1.8 Field 9= Operating Mode; 2 octal digits, right adjusted. Treat as six bits of binary information numbered 1 to 6, left to right; then:

4.1.8.1 Bit 1 is unused

4.1.8.2 Bits 2 and 3 are a two-bit number of locked radars. If less than this number are locked, activate own interrogator.

4.1.8.3 Bit 4, when set, means own interrogator will be activated if passive data shows a threat.

4.1.8.4 Bit 5 when set means top antenna should be used.

4.1.8.5 Bit 6 when set means bottom antenna should be used.

4.1.9 Field 10 = Maximum TOA; LSB = 0.145 μs, 5 octal digits right adjusted.

4.1.10 Field 11 = widened azimuth window - full width, in fraction of 180 degrees, binal point to left of 5 octal digits (40000 = 90 degrees)

4.1.11 Field 12 = Altitude window above own, 2's complement value in units of 100 feet, 6 octal digits from 16-bit machine.

4.1.12 Field 13 = Altitude window below own, 2's complement value in units of 100 feet, 6 octal digits from 16-bit machine.

4.2 Type 0-2 Header

4.2.1 Fields 1 and 2 = 0 and 2 respectively

4.2.2 Always immediately follows a type 0-1 record

4.2.3 Fields 3 through 15 = up to 78 alphanumeric characters entered as a title, left adjusted

4.3 Type 1-1 Main Beam Interrupts

4.3.1 Fields 1 and 2 = 1 and 1

4.3.2 Present by default, deselectable, occur as record is filled.

4.3.3 Fields 3 and 4 = time of interrupt; double word internal clock; LSB = 0.145 μsec, 6 + 6 octal digits from 16-bit machine.

4.3.4 Fields 5 through 14 taken in pairs; time of interrupt as in Fields 3 and 4.

4.3.5 Field 15 = six - 2-bit fields indicating interrogation mode, written as 4 octal digits right adjusted.

4.3.5.1 The mode of the first interrupt (fields 3 & 4) is indicated in the least significant two bits.

4.3.5.2 Bit coding: 00 = nothing, 01 = Mode A, 10 = Mode C, 11 = other mode.

4.4 Type 2-1 Recognized and Locked Radars

4.4.1 Fields 1 and 2 = 2 and 1 respectively

4.4.2 Always present, occurs once per scan, per radar.

4.4.3 Fields 3 and 4 = time of beam center, double word internal clock, LSB = 0.145 μsec, 6 + 6 octal digits from 16 bit machine.

4.4.4 Field 5 = Scan #, 6 octal digits, from 16-bit machine.

4.4.5 Field 6 = mode interlace pattern; 8 - 2-bit fields; 6 octal digits.

4.4.5.1 two most significant bits for oldest interrogation.

4.4.5.2 bit coding: 00 = nothing, 01 = Mode A, 10 = Mode C, 11 = other mode.

4.4.6 Fields 7 through 14 = PRP's; LSB = 0.145 μsec; 6 octal digits from 16-bit machine.

4.4.6.1 Field 7 = PRP1, remaining PRP's in sequence.

4.4.7 Field 15 = number of hits in main beam; 5 octal digits right adjusted.

4.5 Type 2-2 Recognized and Locked Radars

4.5.1 Fields 1 and 2 = 2 and 2

4.5.2 Always immediately following a type 2-1 record

4.5.3 Fields 3 and 4 = time of indicated interrogation; (only if locked) double word internal clock, LSB = 0.145 μsec., 6 + 6 octal digits from 16-bit machine.

4.5.4 Field 5 = number of PRP which immediately follows above interrogation (only if locked), 2 octal digits right adjusted (first PRP is #1)

4.5.5 Fields 6 and 7 = Scan period, double word; LSB = 0.145 μs; 6 + 6 octal digits from 16-bit machine.

4.5.6 Field 8 = internal ID #(plus 1000_8 if locked) 4 octal digits right adjusted.

4.5.7 Field 9 = short main beam count (only if locked) 5 octal digits right adjusted.

4.5.8 Field 10 = External ID - alphabetic (only if locked), up to 6 characters, left adjusted.

4.5.9 Field 11 = number of found interrogations/scan (only if locked), 5 octal digits, right adjusted.

4.5.10 Field 12 = number of missed interrogations/scan (only if locked), 5 octal digits, right adjusted.

4.5.11 Field 13 = number of found interrogations in the widened azimuth window (only if locked) 5 octal digits, right adjusted.

4.5.12 Field 14 and 15 = Error sum (only if locked) double word, LSB = 0.145/(2**16) μsec, 6 + 6 octal digits from a 16-bit machine.

This is the error sum at the time of the indicated interrogation.

4.6 Type 2-3 Recognized and Locked Radars

4.6.1 Fields 1 and 2 = 2 and 3 respectively

4.6.2 Immediately follows a type 2-2 record if the radar is locked.

4.6.3 Field 3 = quality number, 5 octal digits, right adjusted.

4.6.4 Field 4 = own altitude, 2's complement value in units of 100 feet, 6 octal digits from 16-bit machine.

4.6.5 Field 5 = azimuth WRT north, in BAM's, 6 octal digits from 16-bit machine.

45 deg = 020000, 90 deg = 040000,
135 deg = 060000, 180 deg = 100000,
225 deg = 120000, 270 deg = 140000,
315 deg = 160000.

4.6.6 Field 6 = heading of aircraft, in BAM's, 6 octal digits from 16-bit machine.

4.6.7 Field 7 = Own azimuth update flag in bit 0 + No. of P(N)'s in latest scan.

4.7 Type 3-1 Raw Replies

4.7.1 Field 1 and 2 = 3 and 1 respectively.

4.7.2 Normally absent, may be selected; occurs after widened azimuth window of selected radar.

4.7.3 Field 3 = internal ID # of radar, 3 octal digits right adjusted.

4.7.4 Field 4 = scan #, 5 octal digits, right adjusted.

4.7.5 Field 5 = number of interrogation table entries, 5 octal digits, right adjusted.

Table entries are on type 3-2 records

4.7.6 Field 6 = number of replies, 5 octal digits, right adjusted.

Replies occur on type 3-3 records.

4.8 Type 3-2 Raw Replies (interrogation table)

4.8.1 Field 1 and 2 = 3 and 2 respectively.

4.8.2 As many of these records as is required follow immediately after the type 3-1 record. Occur only if type 3-1 occurs.

4.8.3 Fields 3 and 4 = interrogation time, double word, internal clock, LSB = 0.145 μsec., 6 + 6 octal digits from 16-bit machine.

4.8.4 Field 5 = reply number plus one of last reply for this interrogation, reply numbers start at one.

Starting from the first interrogation, if there are 2, 1 and 3 replies, those numbers will be 3, 4 and 7.

4.8.5 Fields 6 through 14, taken in threes = time of interrogation and reply number plus one of last reply as in fields 3 through 5.

4.8.6 Field 15 = four 2-bit fields indicating interrogation mode, written as 3 octal digits right adjusted.

4.8.6.1 The mode of the last interrogation on this record (fields 3 through 5) is indicated in the least significant two bits.

4.8.6.2 Bit coding; 00 = nothing, 01= Mode A, 10 = Mode C, 11 = other mode.

4.9 Type 3-3 Raw Replies (replies)

4.9.1 Fields 1 and 2 = 3 and 3

4.9.2 As many of these records as is required follow immediately after the group of type 3-2 records, occur only if type 3-1 occurs.

4.9.3 Field 3 = reply time, LSB = 0.145 μs, 6 octal digits from 16-bit machine.

4.9.4 Field 4 = reply code plus 4 additional bits 6 octal digits from 16-bit machine.

starting from the most significant bit: F1 not required (within own reply time); miss - reply preceeding this was missed.

SPI pulse

X pulse

A4, A2, A1, B4, B2, B1, C4, C2, C1, D4, D2, D1.

4.9.5 Fields 5 through 14 in pairs = time and reply code for additional replies, written as fields 3 and 4.

4.10 Type 4-1 First Correlated Targets (1 scan, 1 radar)

4.10.1 Fields 1 and 2 = 4 and 1 respectively

4.10.2 Normally present, may be deselected, occurs after widened azimuth window for each radar, if any replies meet the criteria for first correlation.

4.10.3 Field 3 = scan #, 5 octal digits, right adjusted.

4.10.4 Field 4 = radar internal ID # times 400 (8) plus internal target #, written as 5 octal digits right adjusted.

4.10.5 Field 5 = combined Mode A code, written as 4 octal digits, right adjusted (A, B, C, D)

The Mode A code may be replaced by either of two error codes:
177761(8) = Garbled
177760(8) = Insufficient data
These are written as 6 octal digits from a 16-bit machine.

4.10.6 Field 6 = number of hits (= # of raw replies into this correlated reply); 5 octal digits, right adjusted.

4.10.7 Field 7 = TOA (corrected for all circuit delays) LSB = 0.01 μs, 5 octal digits right adjusted.

4.10.8 Field 8 = differential azimuth, in BAM's positive angle if target center occurs after own center, 6 octal digits from 16-bit machine.

45 deg = 020000, 90 deg = 040000,
-45 deg = 160000, -90 deg = 140000.

4.10.9 Field 9 = altitude target, 2's complement value in units of 100 feet, 6 octal digits from 16-bit machine.

the altitude may be replaced by any of four error codes:
177761(8) = Garbled
177760(8) = Insufficient data
100000(8) = No Mode C received
140000(8) = Illegal conversion

4.10.10 Fields 10-15 = information for another target, written like fields 4 through 9.

4.11 Type 5-1 Second Correlated Tracks (multi-scan, 1 radar)

4.11.1 Fields 1 and 2 = 5 and 1 respectively

4.11.2 Normally present, may be deselected, occurs after widened azimuth window for each radar, if any targets meet the criteria for second correlation.

4.11.3 Field 3 = scan #, 5 octal digits, right adjusted.

4.11.4 Field 4 = radar internal ID #, 3 octal digits, right adjusted.

4.11.5 Field 5 = local track # *100(8) plus internal target #.

4.11.6 Fields 6 through 15 = local track and internal target # for additional tracks.

4.12 Type 6-1 Third Correlated Global Tracks (multi-scan, multi radar)

4.12.1 Field 1 and 2 = 6 and 1 respectively

4.12.2 Normally present, may be deselected. Occurs after widened azimuth window for each radar, if any tracks meet the criteria for third correlation.

4.12.3 Field 3 = scan #, 5 octal digits, right adjusted.

4.12.4 Field 4 = radar internal ID #, 3 octal digits, right adjusted.

4.12.5 Field 5 = local track # * 100 (8) + global track #.

4.12.6 Fields 6 through 15 = global track and track # for additional tracks.

4.13 Type 7-1 Threat Information

4.13.1 Fields 1 and 2 = 7 and 1 respectively.

4.13.2 Normally present, may be deselected. Occurs once each 2.5 seconds.

4.13.3 Field 3 = radar bits * 100(8) + global track #
6 octal digits from 16-bit machine.

4.13.4 Field 4 = current time, internal clock.
LSB = 9.5027 ms, 6 octal digits

4.13.5 Fields = target altitude extrapolated to current time. 2's complement value in units of 100 feet, 6 octal digits from 16-bit machine.

4.13.6 Field 6 = target ID, 4 octal digits right adjusted (A, B, C, D)

4.13.7 Field 7 = threat status * 100
received tie breaker bits: bit 13 = Mode C-D1 bit, bit 14 = Mode C - X bit, bit 15 (LSB) = Mode A - X bit

4.13.8 Field 8 = TAU Ø word - 6 octal digits from 16-bit machine.

4.13.9 Field 9 = TAU 1 word - 6 octal digits from 16-bit machine.

4.13.10 Field 10 = TAU 2 word - 6 octal digits from 16-bit machine.

4.13.11 Field 11 = TAU 2P word - 6 octal digits from 16-bit machine.

Field 12 = Transmitted tie breaker bits
bit 13 = Mode C-D1 bit, bit 14 = Mode C-X bit
bit 15(LSB) = Mode A-X bit.

Field 13 = Climb/Dive Indicator Word

bit			
2	2K Down	9	1K Up
3	1K Down	10	2K Up
4	500 Down	11	No Turn
5	DIVE	12	200 Up
6	LEVEL	13	200 Down
7	CLIMB	14	
8	500 Up	15	

Field 14 = Own altitude, 2's complement value in units of 100 ft., 6 octal digits from 16-bit machine.

5. NOTES ON READING TAPE

5.1 Conversion of the data on tape to the proper internal form of the processing computer is machine dependent. The conversion of positive values is straight forward but that of signed values is somewhat more complex.

16-bit positive values are a problem on 16-bit machines and 32 bit positive values are a problem on 32-bit machines.

5.2 Conversion of 32-bit time values (unsigned).

5.2.1 Nova (16-bit machine)

```
      READ (12,100) IA, IB, IC, ID
100 FORMAT (I1, OI5, I1, OI5)
      IF (IA. NE.0) IB = IB. OR. 100000K
      IF (IC. NE.0) ID = ID. OR. 100000K
```

5.2.2 CDC 6600 (60 bit machine)

```
      READ (12,100)  IA, IB
      100 FORMAT (O6, O6)
            IB = IA * 65536 + IB
```

5.3 Conversion of Date & Time

```
READ (12,100) IMNTH, IDAY, IYR, IHR, IMN, ISEC, ISCID
100 FORMAT     (I2, I2, I2, 2X, I2, I2, 3X, I2, I1)
```

5.4 Unsigned 5 or fewer octal digit values

5.4.1 Nova (16-bit machine)

```
READ (12,100) IB
100 FORMAT (1X, OI5)
```

5.4.2 COC 6600 (60-bit machine)

```
READ (12,100) IB
100 FORMAT (1X, O5)
```

5.5 Angles in BAM's

5.5.1 Convert the value as if it were a signed integer.

5.5.2 Convert to floating point

5.5.3 Multiply by 90/16384 to convert to degrees or π/32768 to convert to radars.

5.6 Conversion of unsigned 16-bit values

5.6.1 Nova (16-bit machine)

```
READ (12,100) IA, IB
100 FORMAT (I1, OI5)
IF (IA, NE, 0) IB = IB. OR. 100000K
```

5.6.2 COC 6600 (60-bit machine)

```
READ 12,100 IB
100 FORMAT (O6)
```

5.7 Conversion of up to 8 packed interrogation modes.

5.7.1 Read value in as 16-bit unsigned value

5.7.2 Nova (16-bit machine)

```
MD1 = IB. AND.3K
MD2 = ISHFT (IB, -2) . AND.3K
MD8 = ISHFI (IB, -14), AND.3K
```

5.7.3 COC 6600 (60-bit machine)

```
MD1 = IB. AND.3B
MD2 = SHIFT (IB, -2). AND.3B
MD8 = SHIFT (IB, -14). AND. 3B
```

5.8 Conversion of signed 16-bit value

5.8.1 Nova (16-bit machine)

Read it exactly like unsigned 16-bit value.

5.8.2 COC 6600 (60-bit machine, 1's complement)

```
READ (12,100) IA, IB
100 FORMAT (01,05)
    IF (IA. NE.0) IB = -(1+(.NOT.IB.AND.
       77777B))
```

5.9 Conversion of signed 32-bit value (ERROR SUM)

5.9.1 Nova (16-bit machine)

Read it exactly like unsigned 32-bit value (time value)

5.9.2 COC 6600 (60-bit machine, 1's complement)

```
READ (12,100) IA, IB, IC
100 FORMAT (01, 05, 06)
   IB= IB * 65536 + IC
   IF (IA.NE.0) IB= -(1+ (.NOT. IB. AND.
      17777777777B))
```

5.10 Two packed 7-bit bytes in one field

5.10.1 Nova (16-bit machine)

```
READ (12,100) IA
100 FORMAT (1X, OI5)
IL = IA. AND. 177K
IH = ISHFT (IA -8). AND. 177K
```

5.10.2 COC 6600 (60-bit machine)

```
READ (12,100) IA
100 FORMAT (1X, 05)
IL = IA. AND. 177B
IH = SHIFT (IA, -8). AND. 177B
```

APPENDIX F

FIGURES AND TABULAR LISTINGS

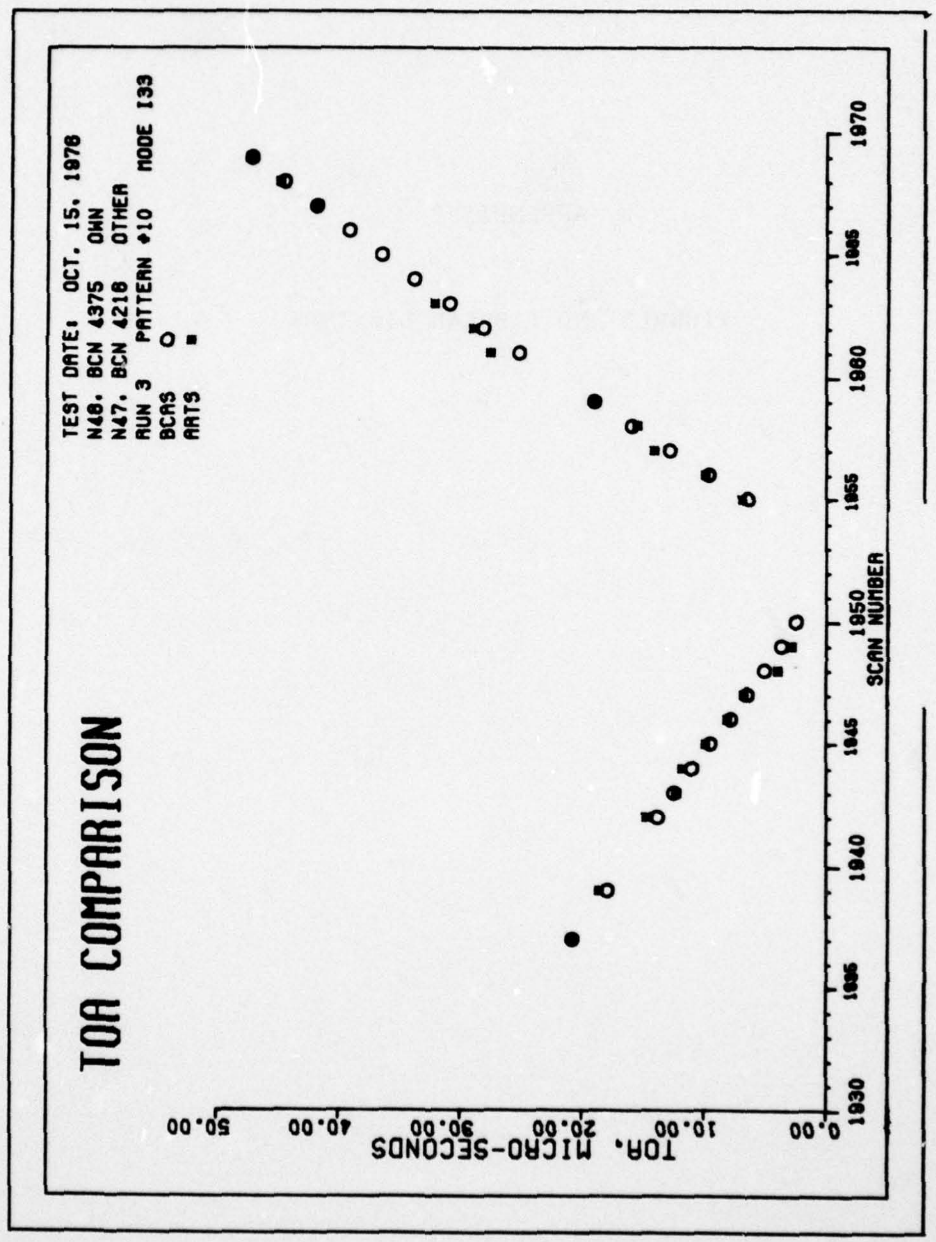

TOA COMPARISON
TEST DATE: OCT. 15, 1978
N46. BCN 4375 OWN
N47. BCN 4218 OTHER
RUN 3 PATTERN #10 MODE I33
BCAS
ARTS
TOA, MICRO-SECONDS
SCAN NUMBER
0.00
10.00
20.00
30.00
40.00
50.00
1930
1935
1940
1945
1950
1955
1960
1965
1970

FIGURE 5.2-1

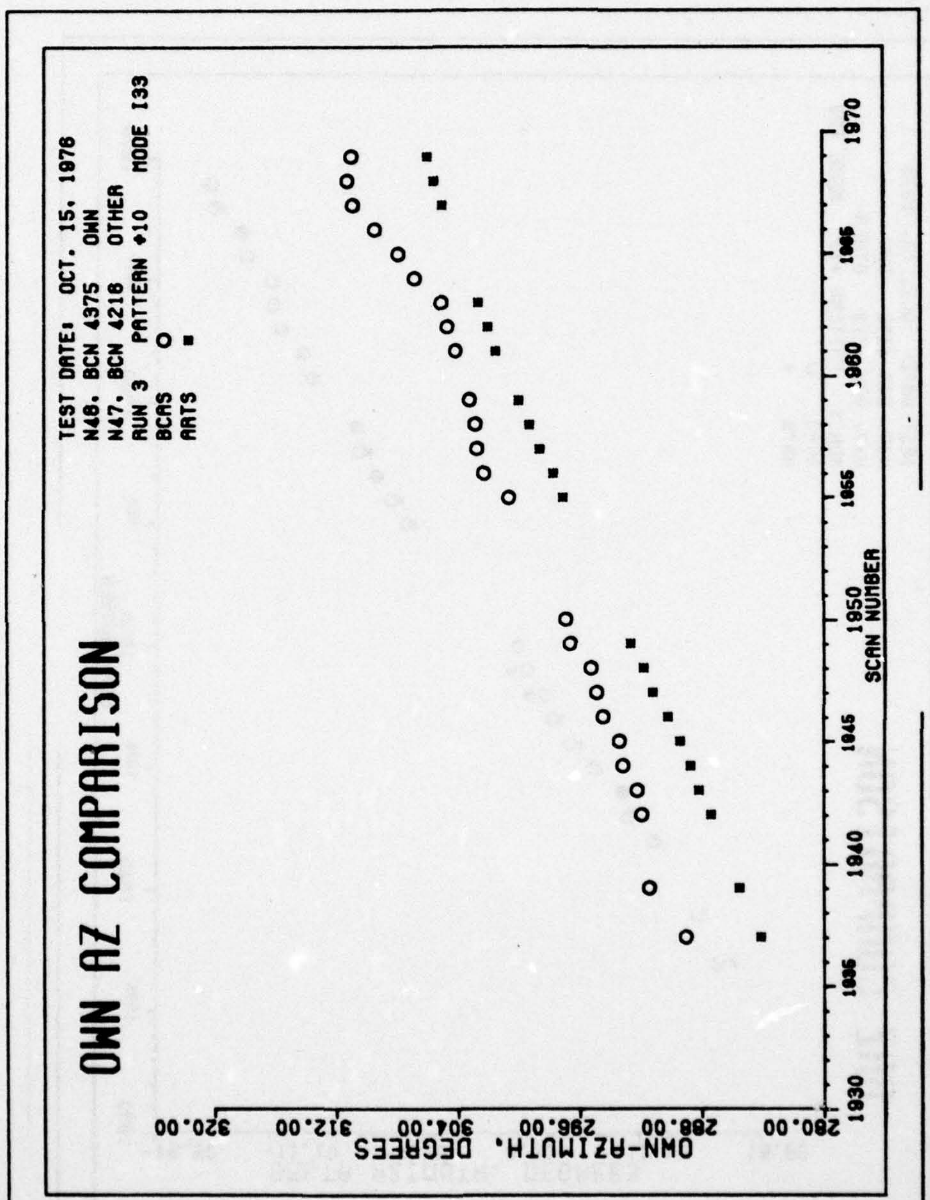

OWN AZ COMPARISON
TEST DATE: OCT. 15, 1976
N46. BCN 4375 OWN
N47. BCN 4216 OTHER
RUN 3 PATTERN #10 MODE I33
BCAS
ARTS
OWN-AZIMUTH, DEGREES
280.00
288.00
296.00
304.00
312.00
320.00
1930
1935
1940
1945
1950
1955
1960
1965
1970
SCAN NUMBER

FIGURE 5.2-2

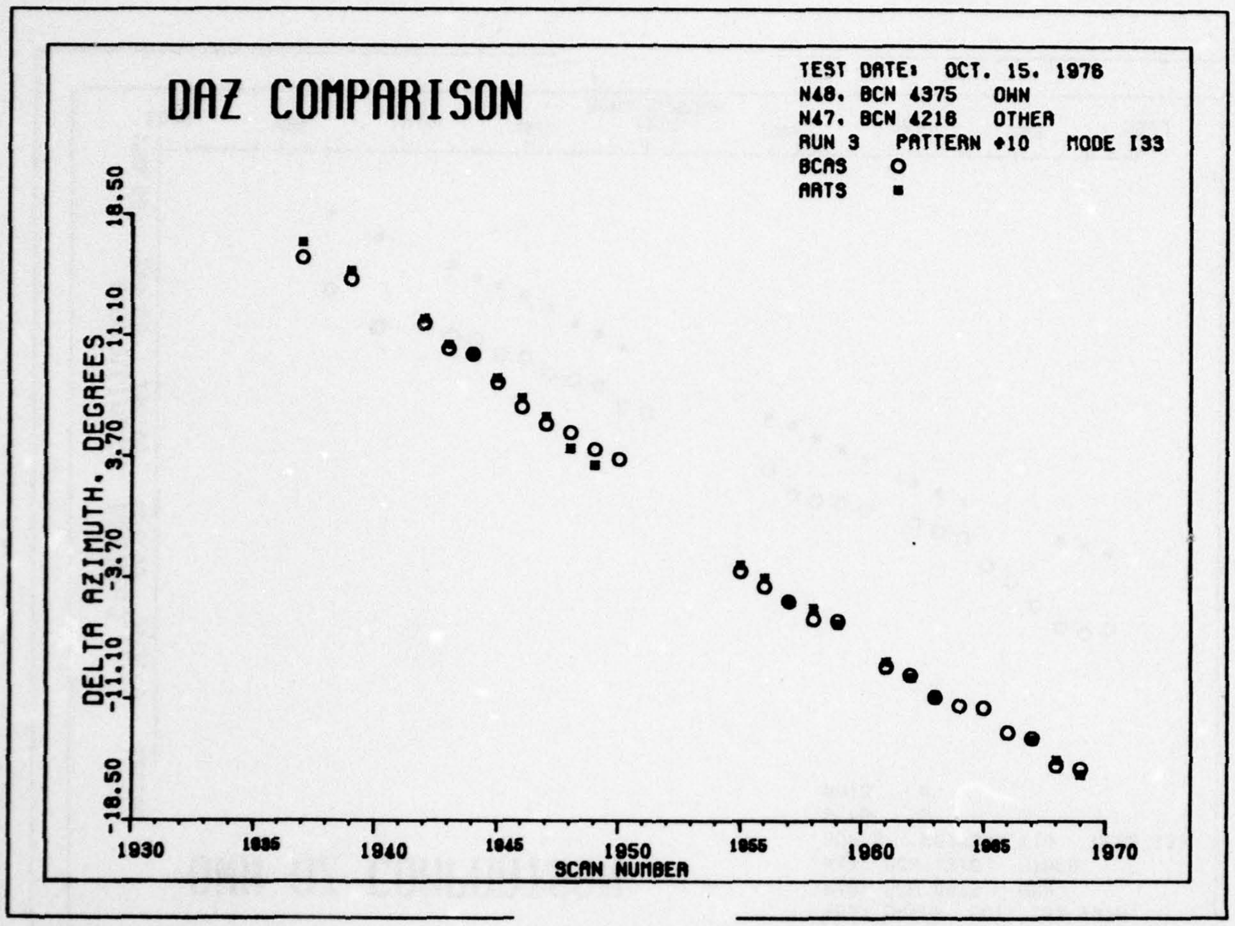
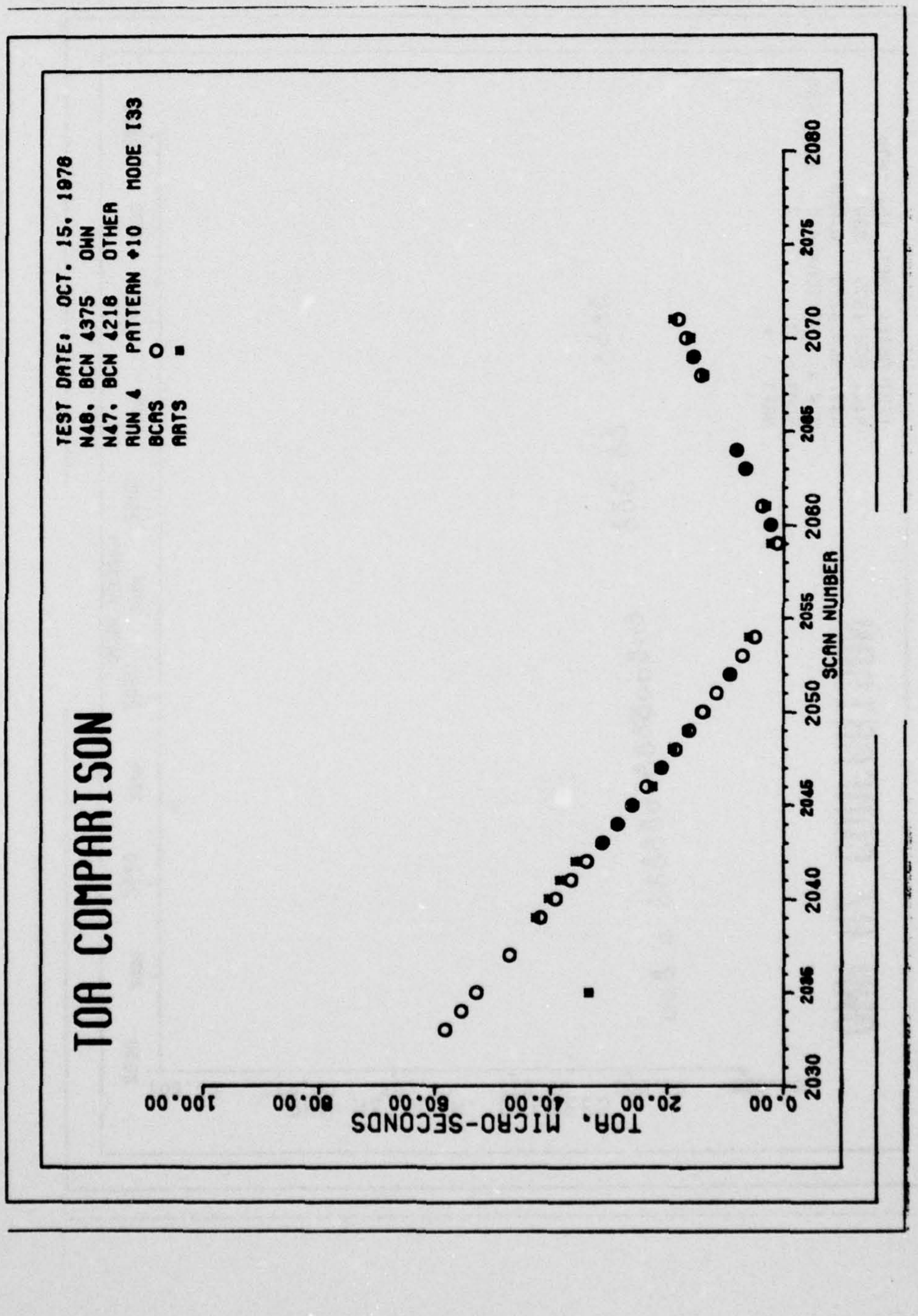
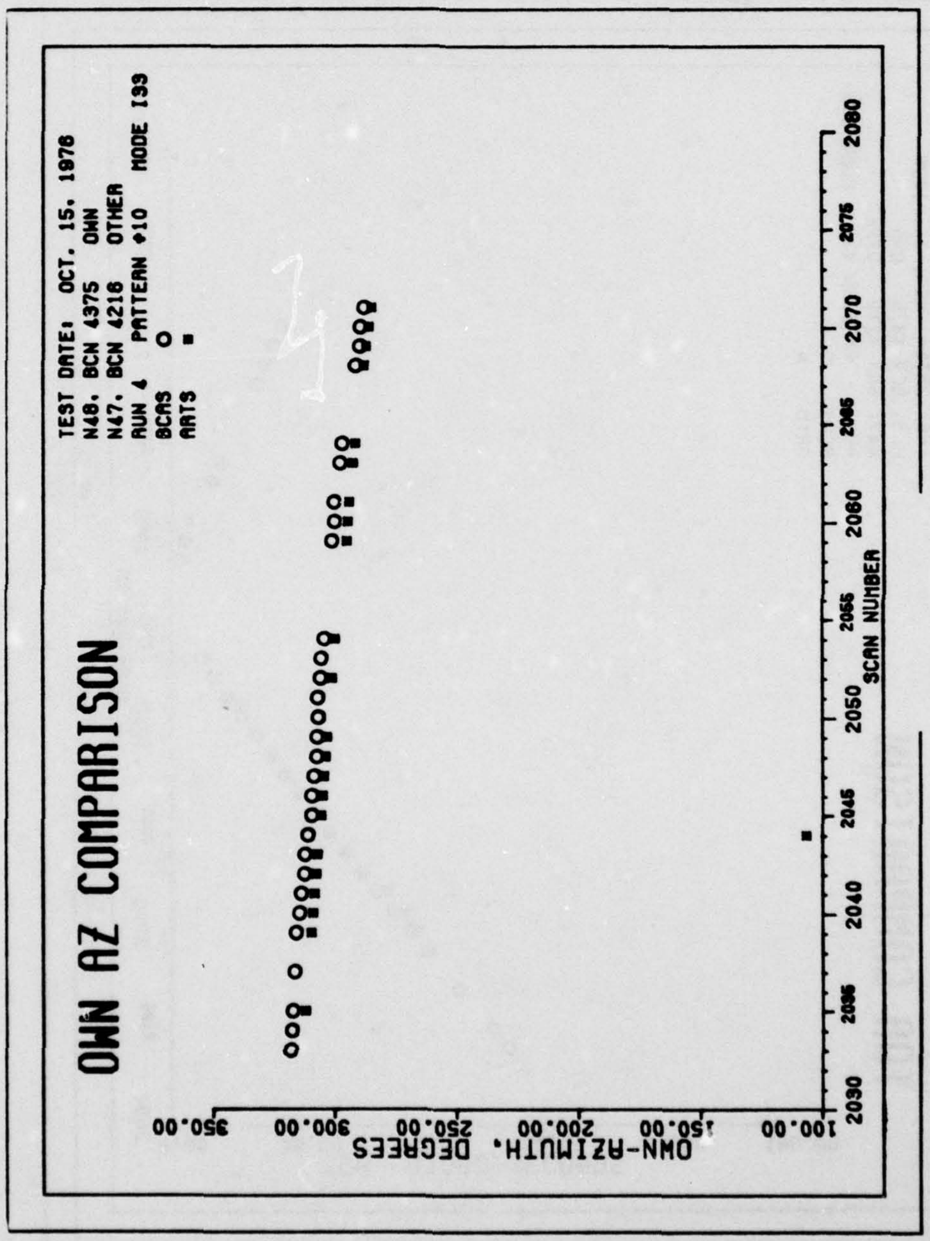

DAZ COMPARISON
TEST DATE: OCT. 15. 1976
N48. BCN 4375 OWN
N47. BCN 4218 OTHER
RUN 3 PATTERN #10 MODE I33
BCAS
ARTS
DELTA AZIMUTH. DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
1930
1935
1940
1945
1950
1955
1960
1965
1970
SCAN NUMBER

FIGURE 5.2-3



TOA COMPARISON
TEST DATE: OCT. 15, 1978
N48. BCN 4375 OWN
N47. BCN 4216 OTHER
RUN 4 PATTERN #10 MODE I33
BCAS
ARTS
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080

FIGURE 5.2-4



OWN AZ COMPARISON
TEST DATE: OCT. 15, 1976
N48, BCN 4375 OWN
N47, BCN 4216 OTHER
RUN 4 PATTERN #10 MODE I33
BCAS
ARTS
OWN-AZIMUTH, DEGREES
350.00
300.00
250.00
200.00
150.00
100.00
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
SCAN NUMBER

FIGURE 5.2-5

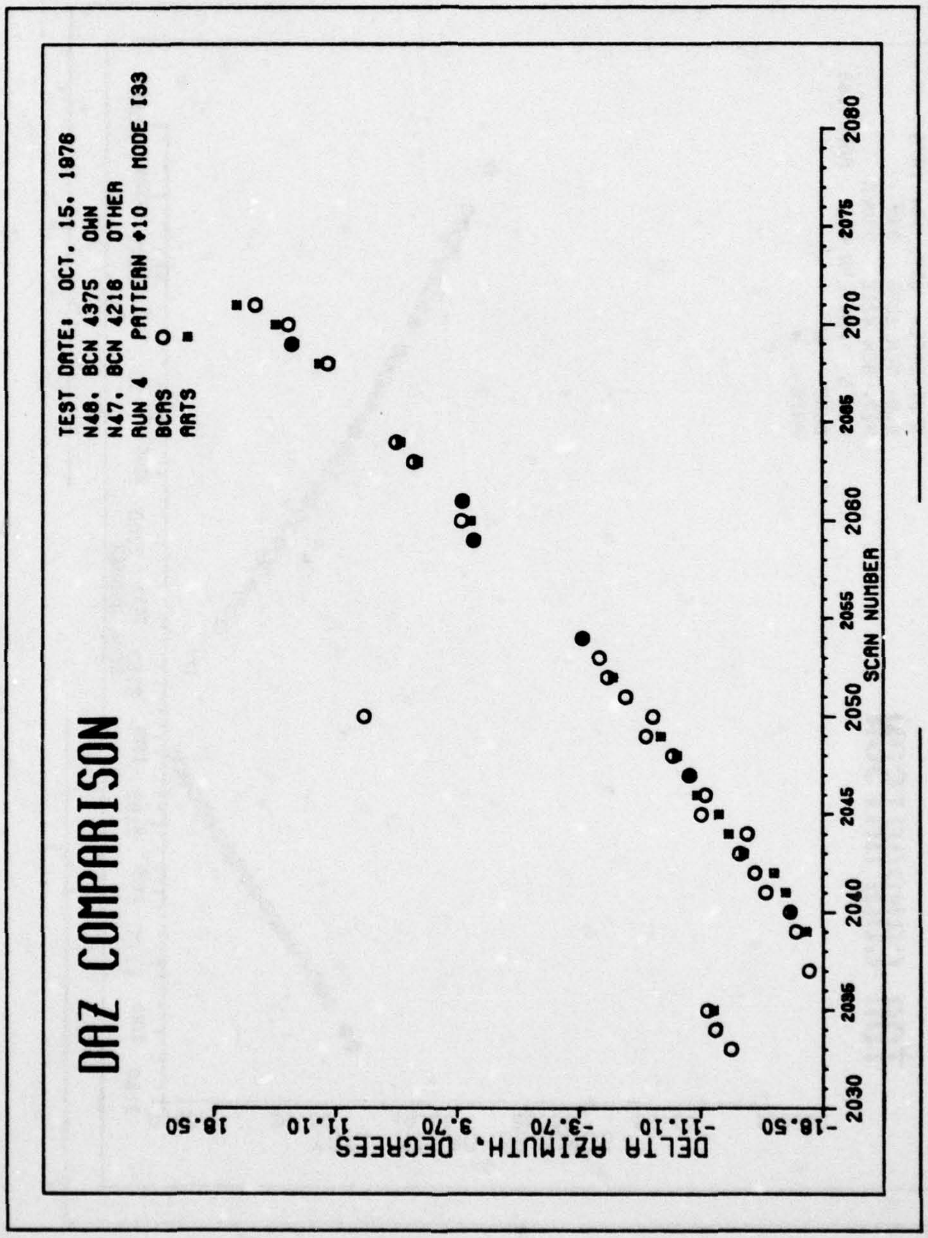

DAZ COMPARISON
TEST DATE: OCT. 15, 1976
N48, BCN 4375 OWN
N47, BCN 4216 OTHER
RUN 4 PATTERN #10 MODE I33
BCAS
ARTS
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080

FIGURE 5.2-6

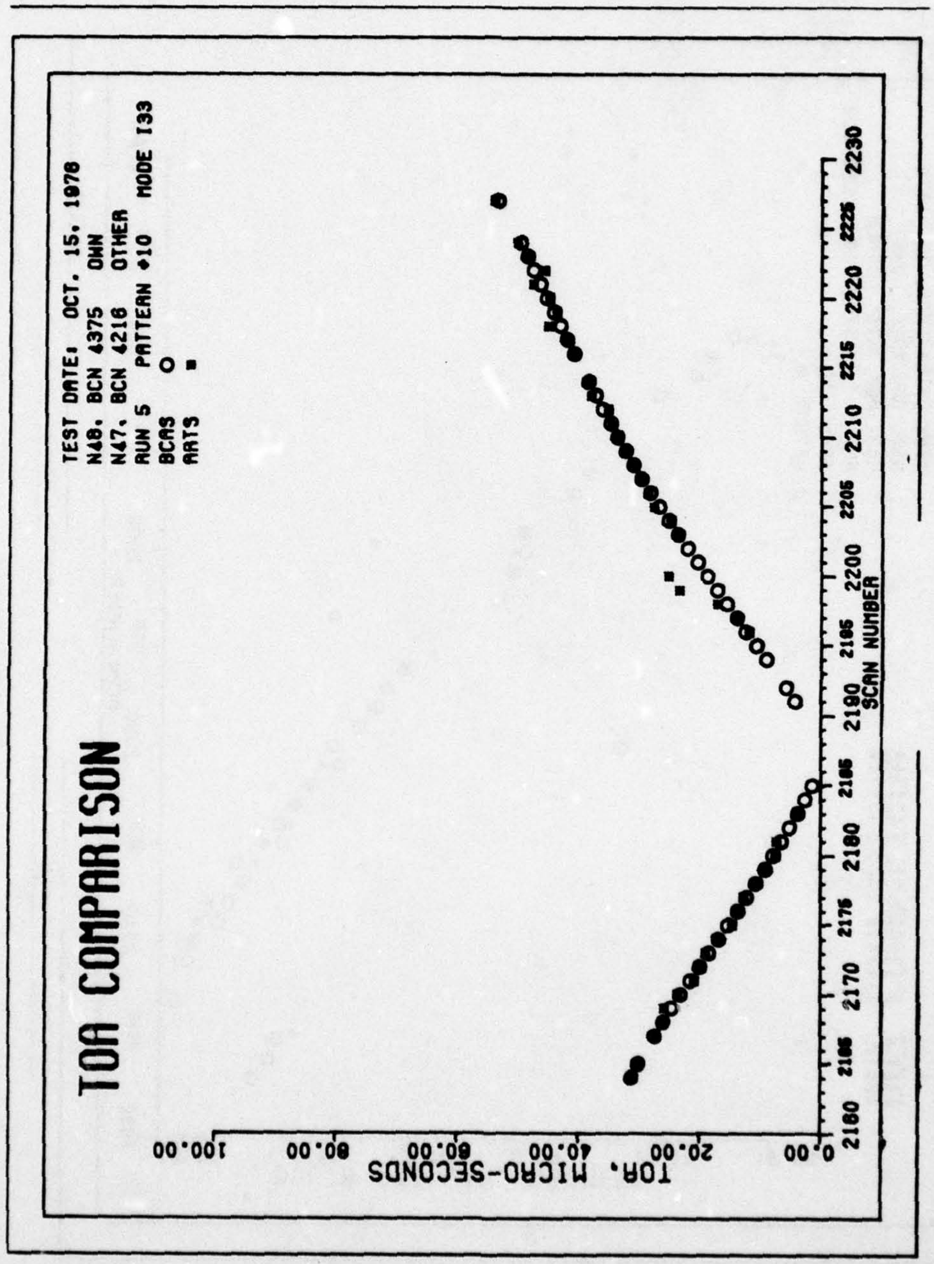

TOA COMPARISON
TEST DATE: OCT. 15, 1978
N48. BCN 4375 OWN
N47. BCN 4216 OTHER
RUN 5 PATTERN #10 MODE I33
BCAS O
AATS ■
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230

FIGURE 5.2-7

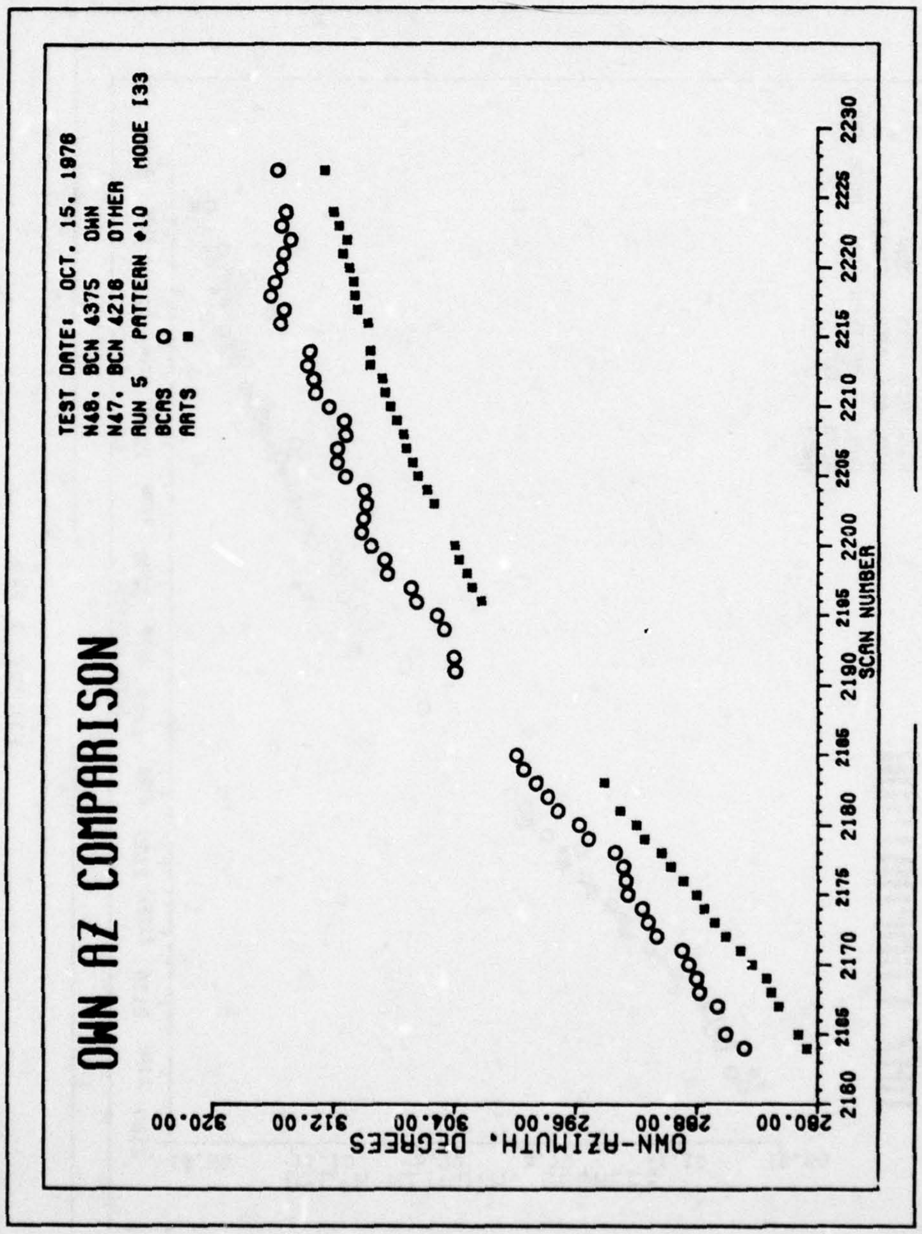
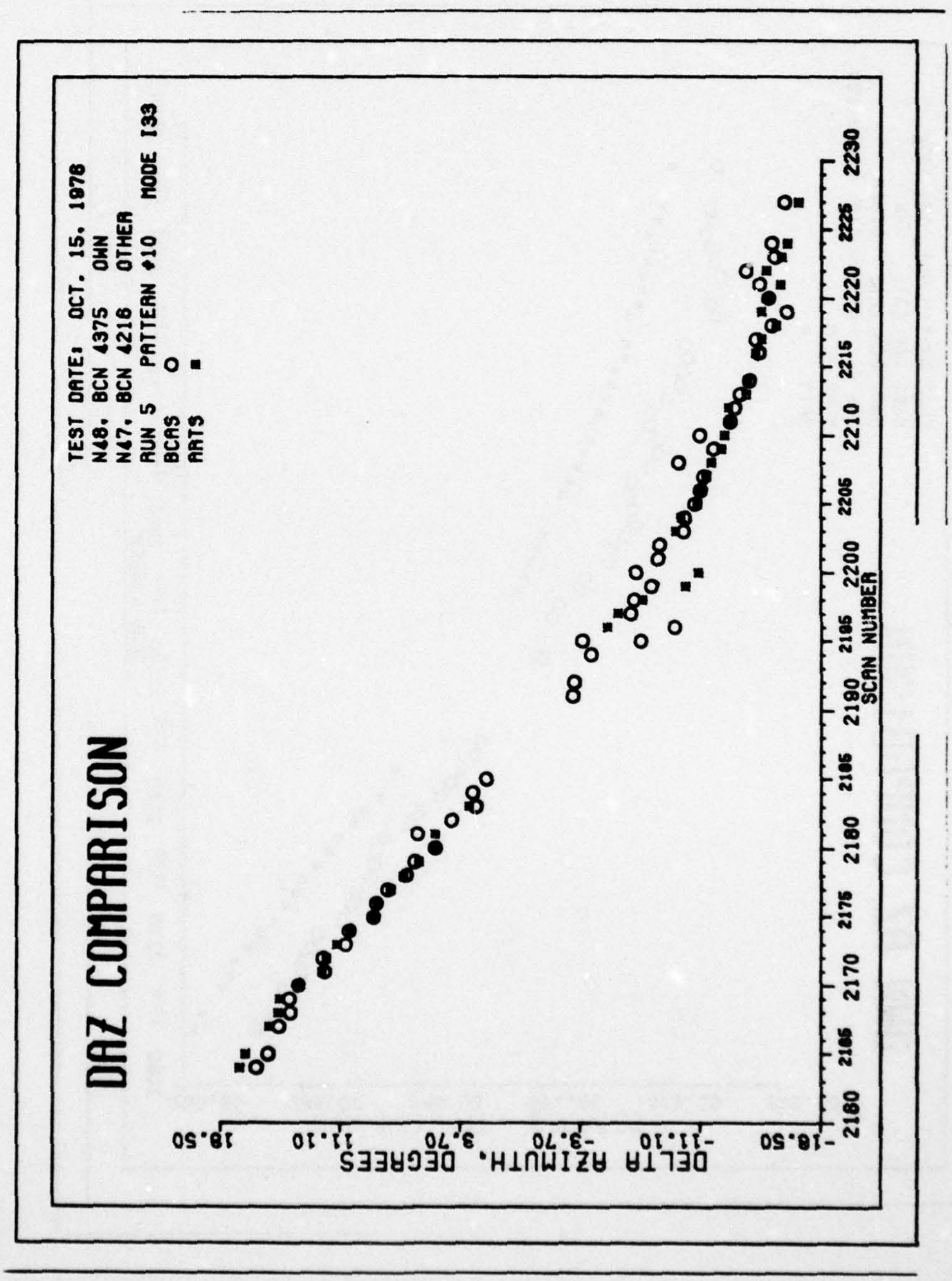
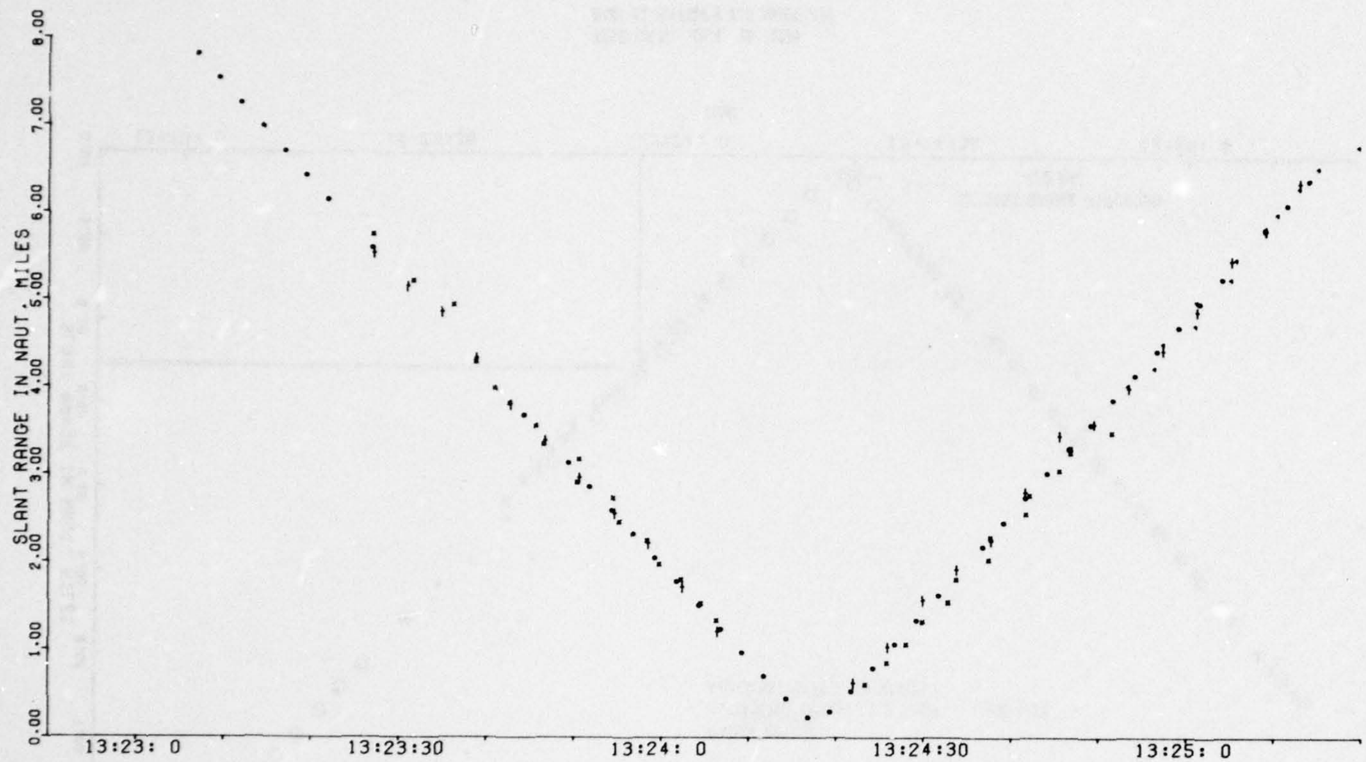

OWN AZ COMPARISON
TEST DATE: OCT. 15, 1976
N48. BCN 4375 OWN
N47. BCN 4218 OTHER
RUN 5 PATTERN #10 MODE I33
BCAS
ARTS
OWN-AZIMUTH, DEGREES
280.00
288.00
296.00
304.00
312.00
320.00
SCAN NUMBER
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230

FIGURE 5.2-8



DAZ COMPARISON
TEST DATE: OCT. 15, 1978
N48, BCN 4375 OWN
N47, BCN 4216 OTHER
RUN 5 PATTERN #10 MODE I33
BCAS
ARTS
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230

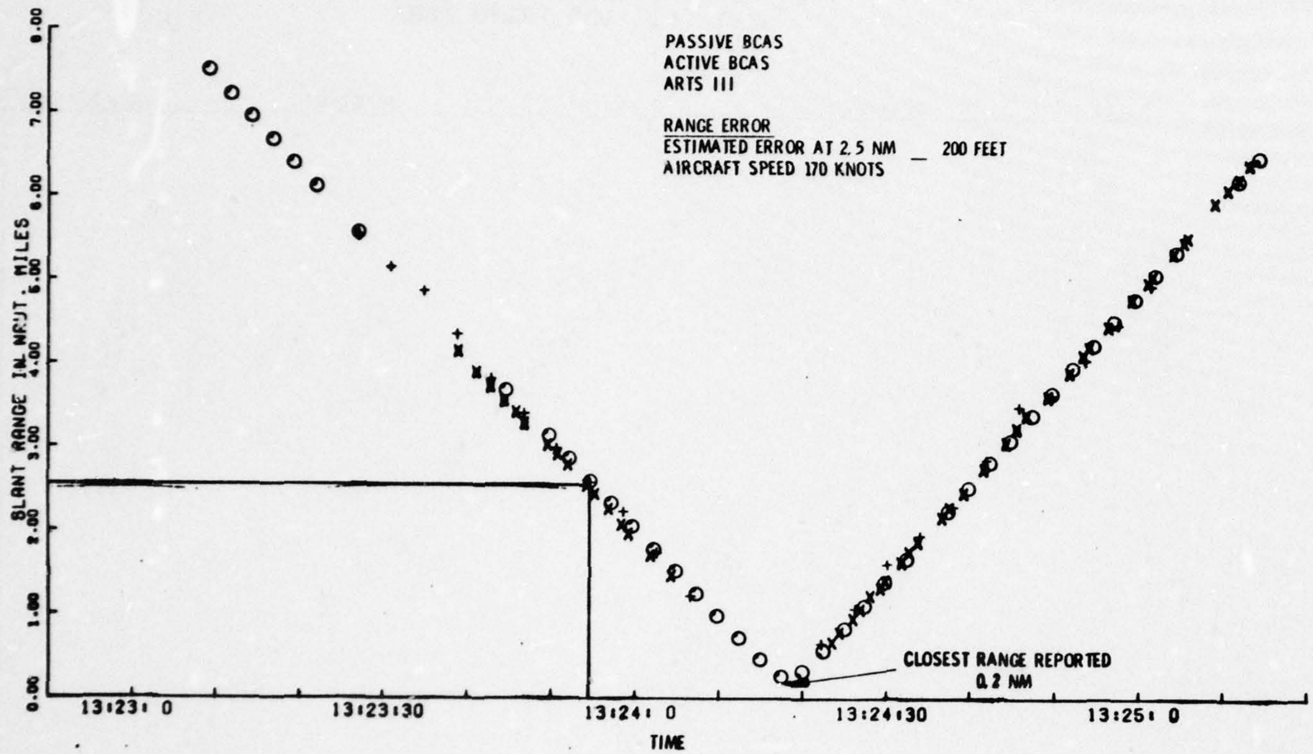
FIGURE 5.2-9



TEST DATE: OCT. 15, 1975
RUN #1 PATTERN #10 MODE I33

UCTS, INC. ANAHEIM, CALIFORNIA CHART NO. 400

FIGURE 5.2-10

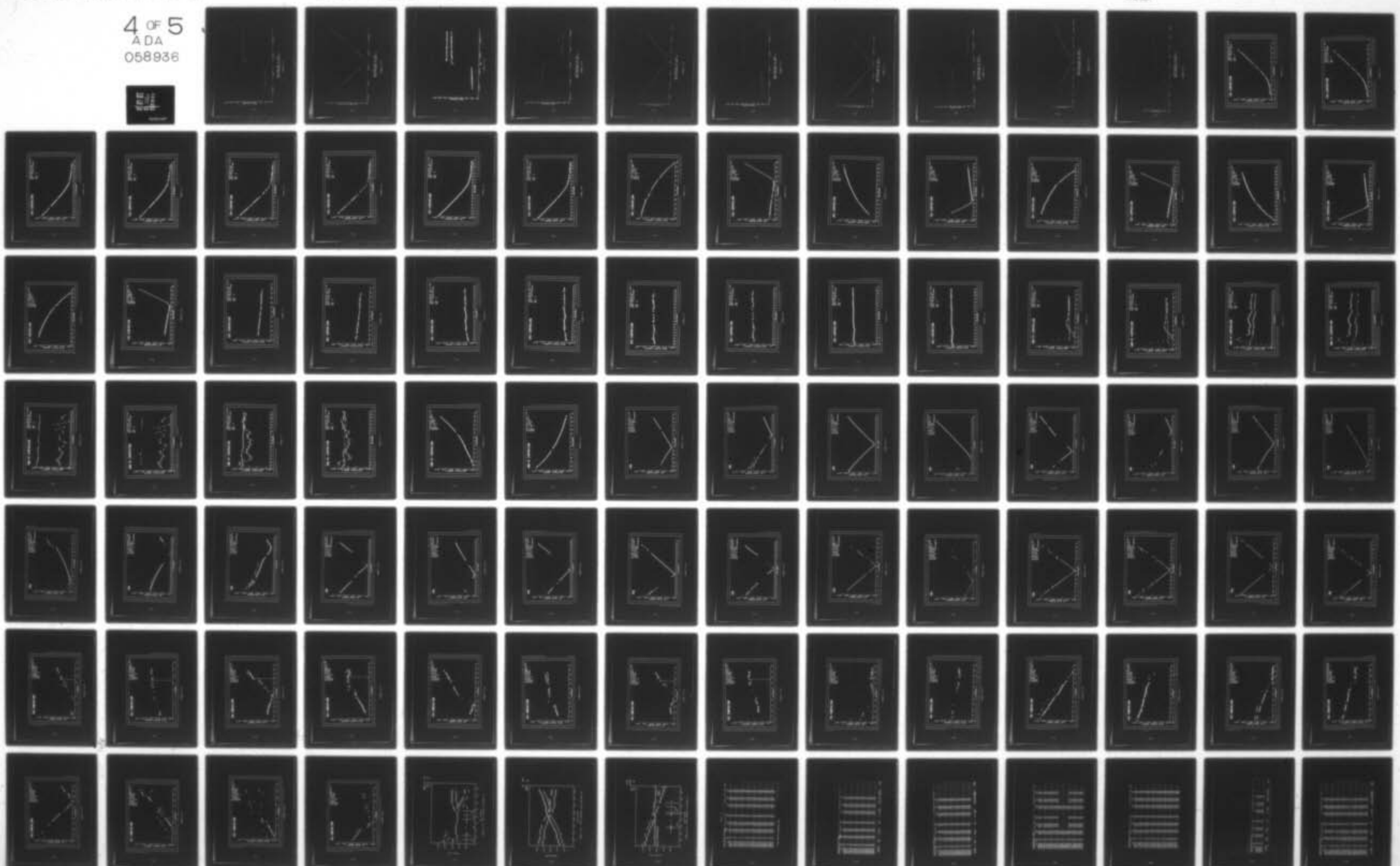


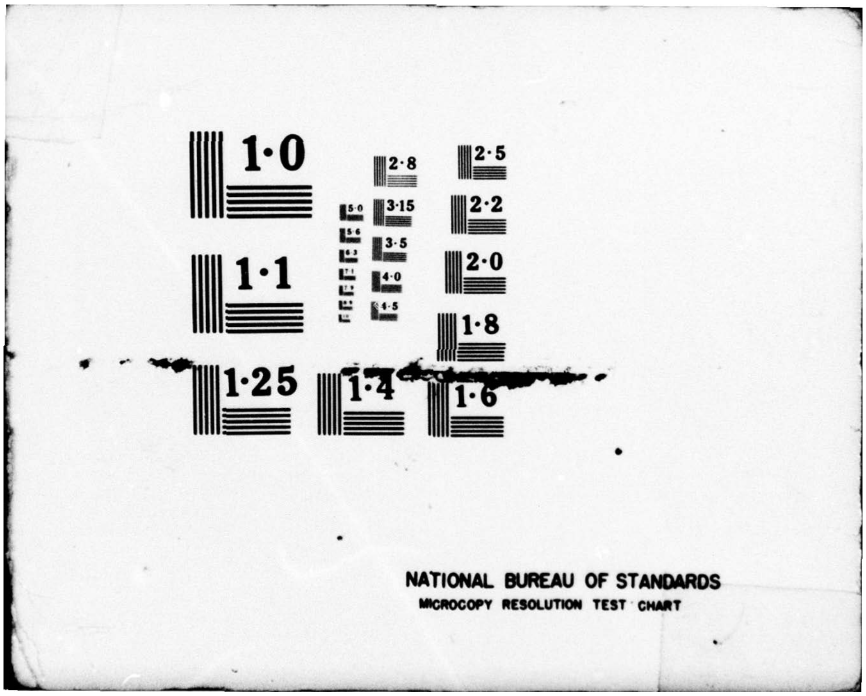
TEST DATE: OCT. 15, 1976
RUN #1 PATTERN #10 MODE 133

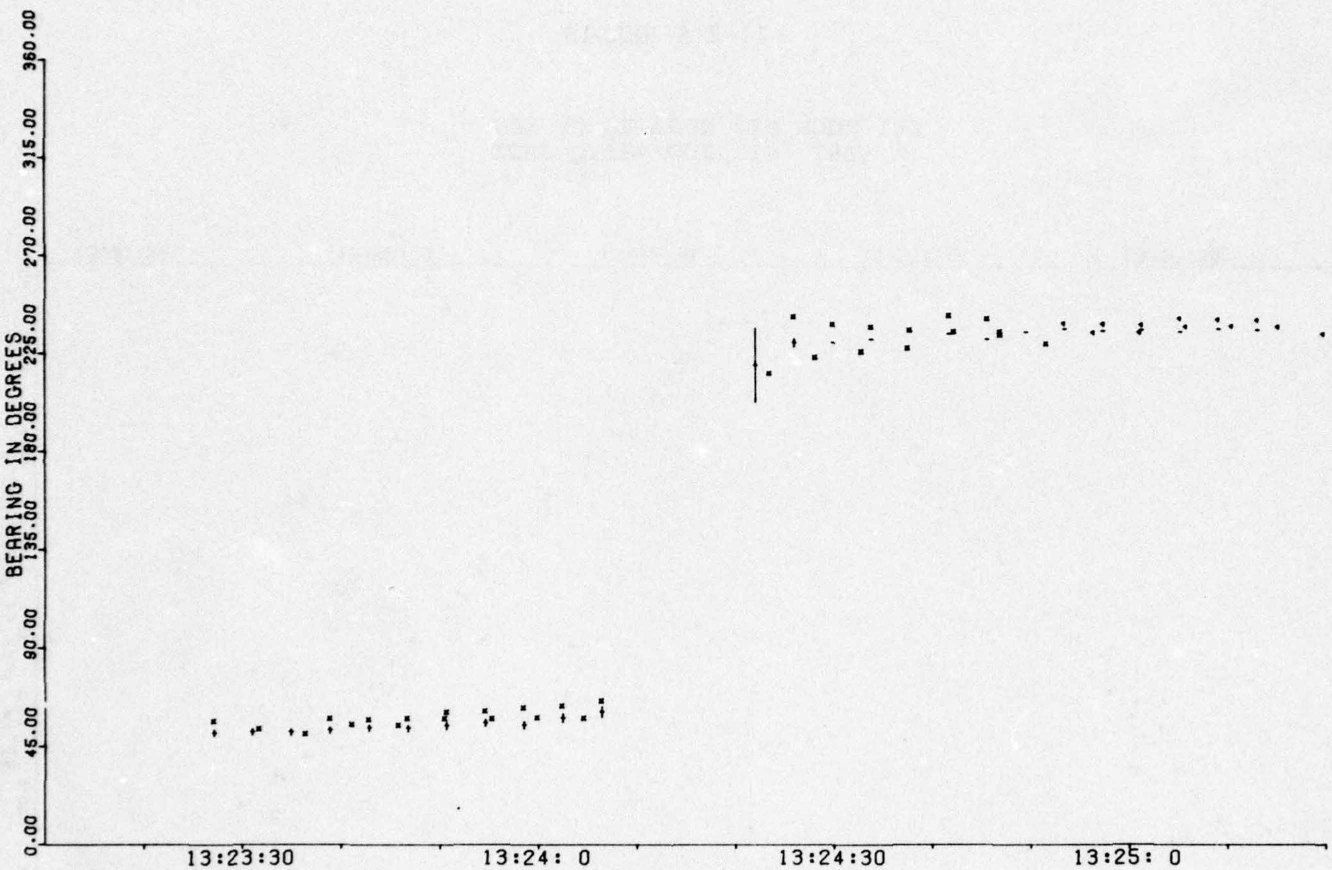
FIGURE 5.2-10a

AD-A058 936 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 1/4
EXPERIMENTAL BCAS PERFORMANCE RESULTS.(U)
JUL 78 J VILCANS, E QUISH, J G RAUDSEPS
UNCLASSIFIED TSC-FAA-78-9 FAA-RD-78-53 NL

4 OF 5
ADA
058936

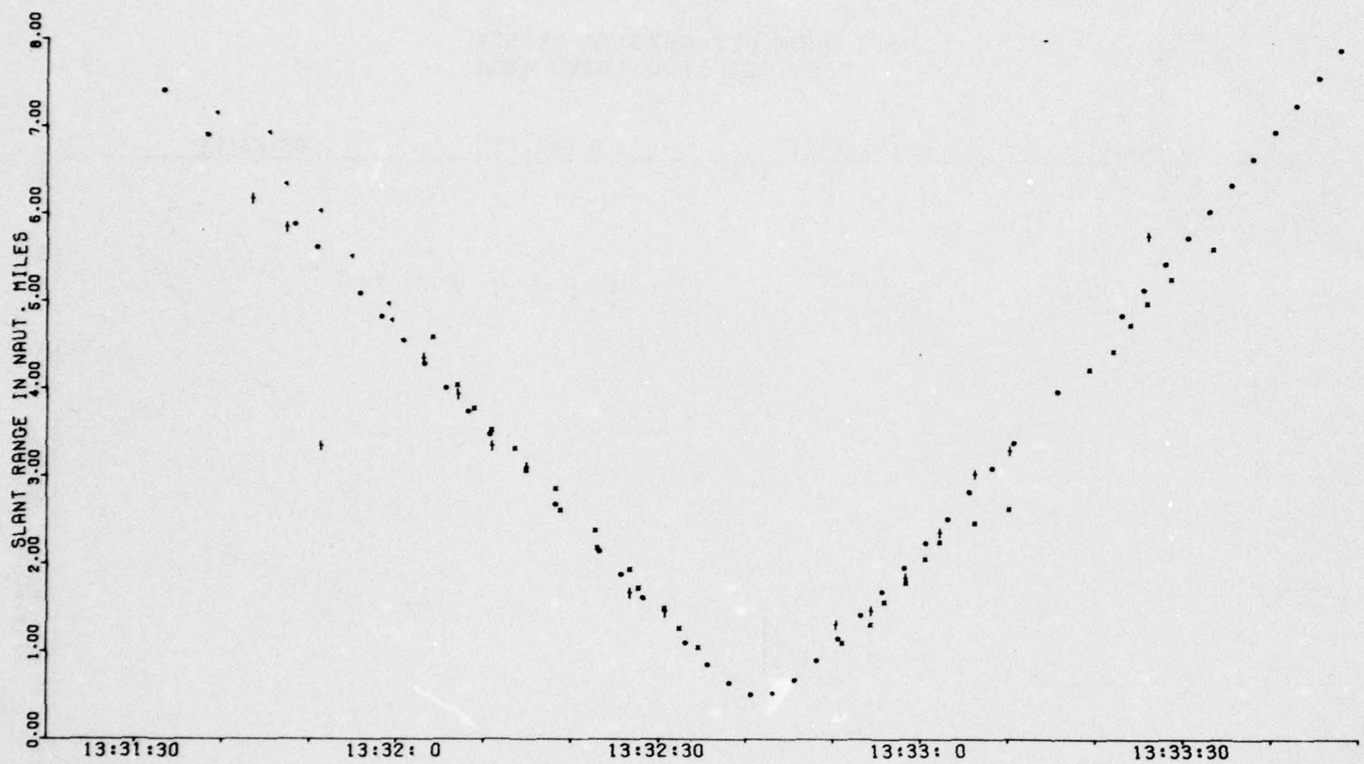



1·0
2·8
2·5
3·15
2·2
3·5
1·1
4·0
2·0
4·5
1·8
1·25
1·4
1·6
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART



TEST DATE: OCT. 15, 1975
RUN #1 PATTERN #10 MODE I33

FIGURE 5.2-11



TEST DATE: OCT. 15, 1975
RUN #2 PATTERN #10 MODE I33

FIGURE 5.2-12

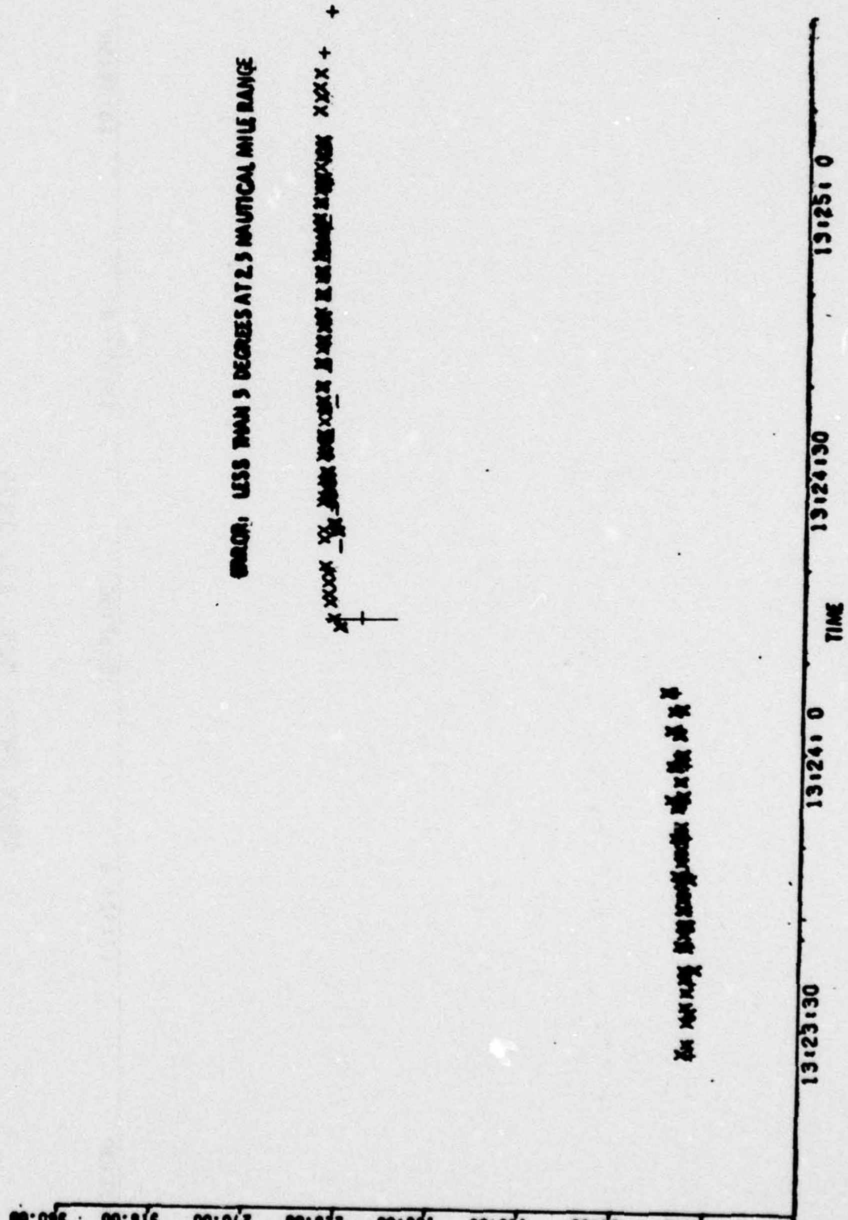
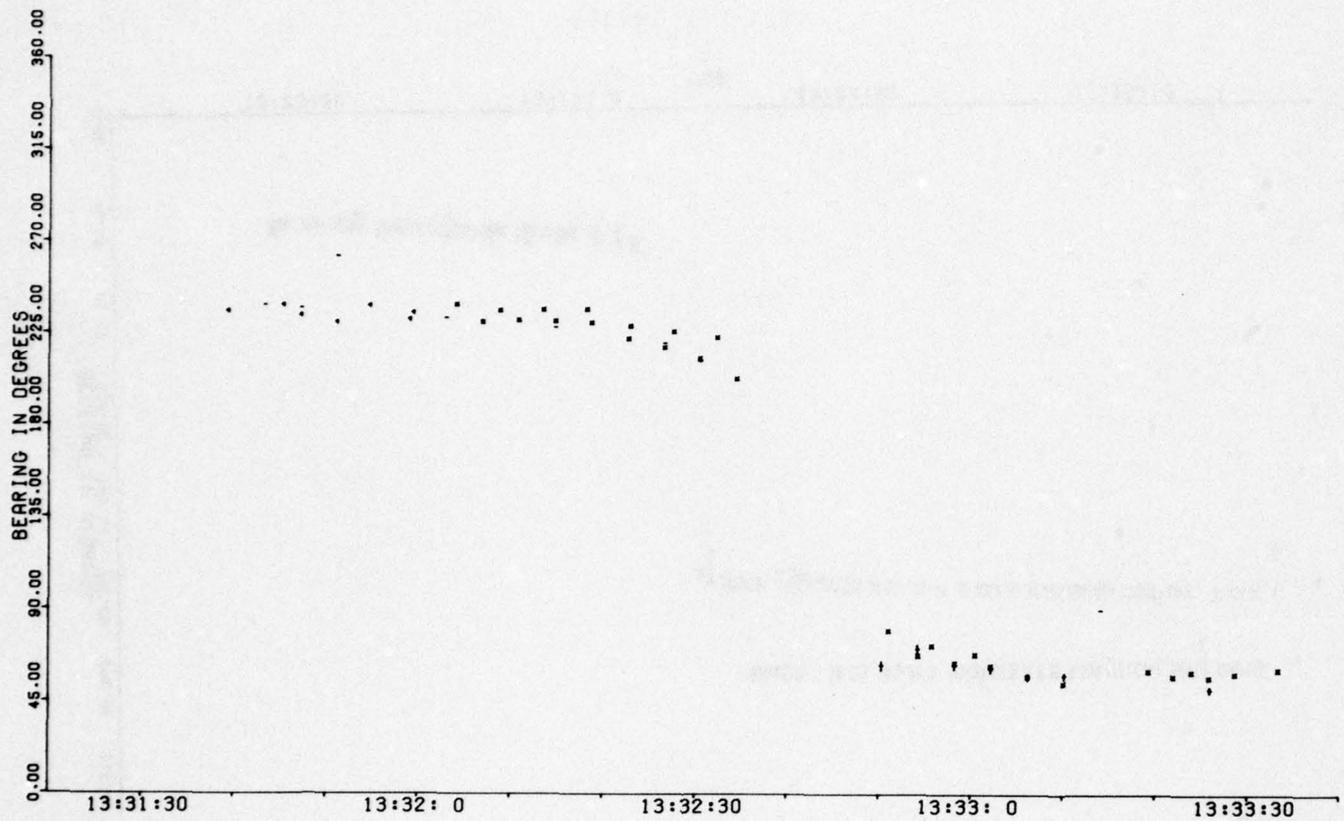
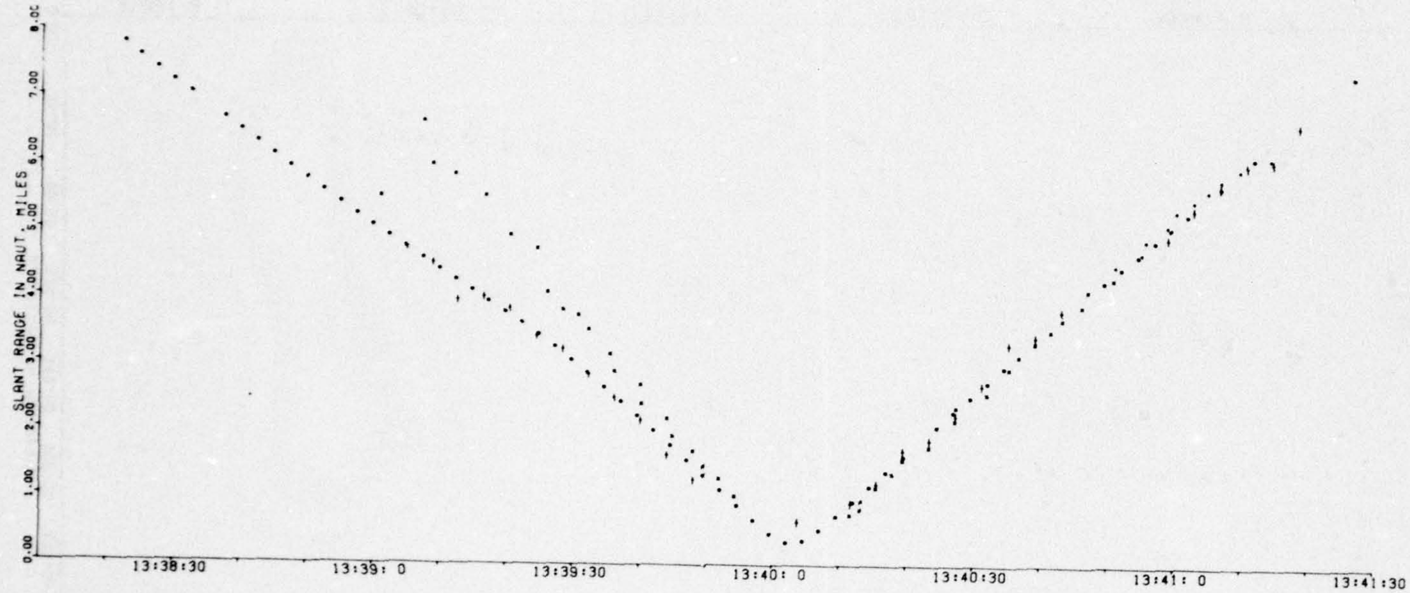


FIGURE 5.2-12a



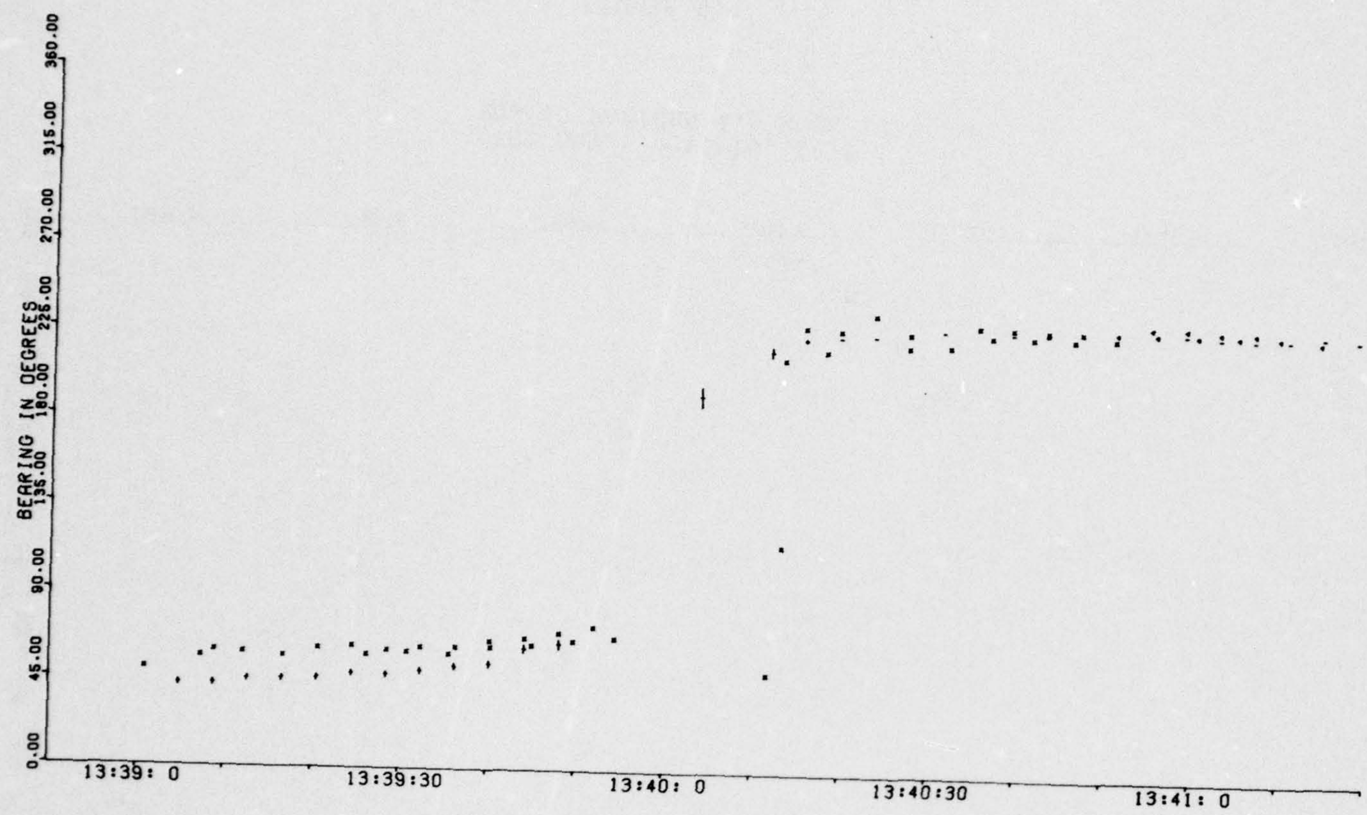
TEST DATE: OCT. 15, 1975
RUN #2 PATTERN #10 MODE I33

FIGURE 5.2-13



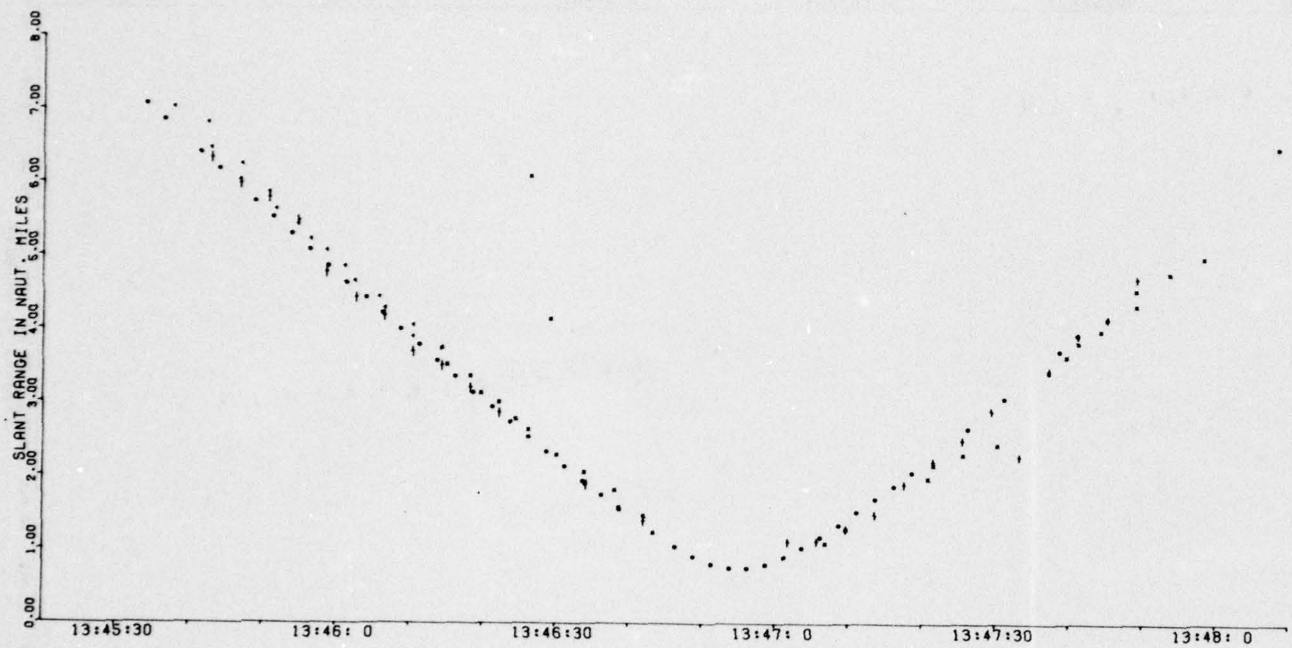
TEST DATE: OCT. 15, 1975
RUN #3 PATTERN #10 MODE I33

FIGURE 5.2-14



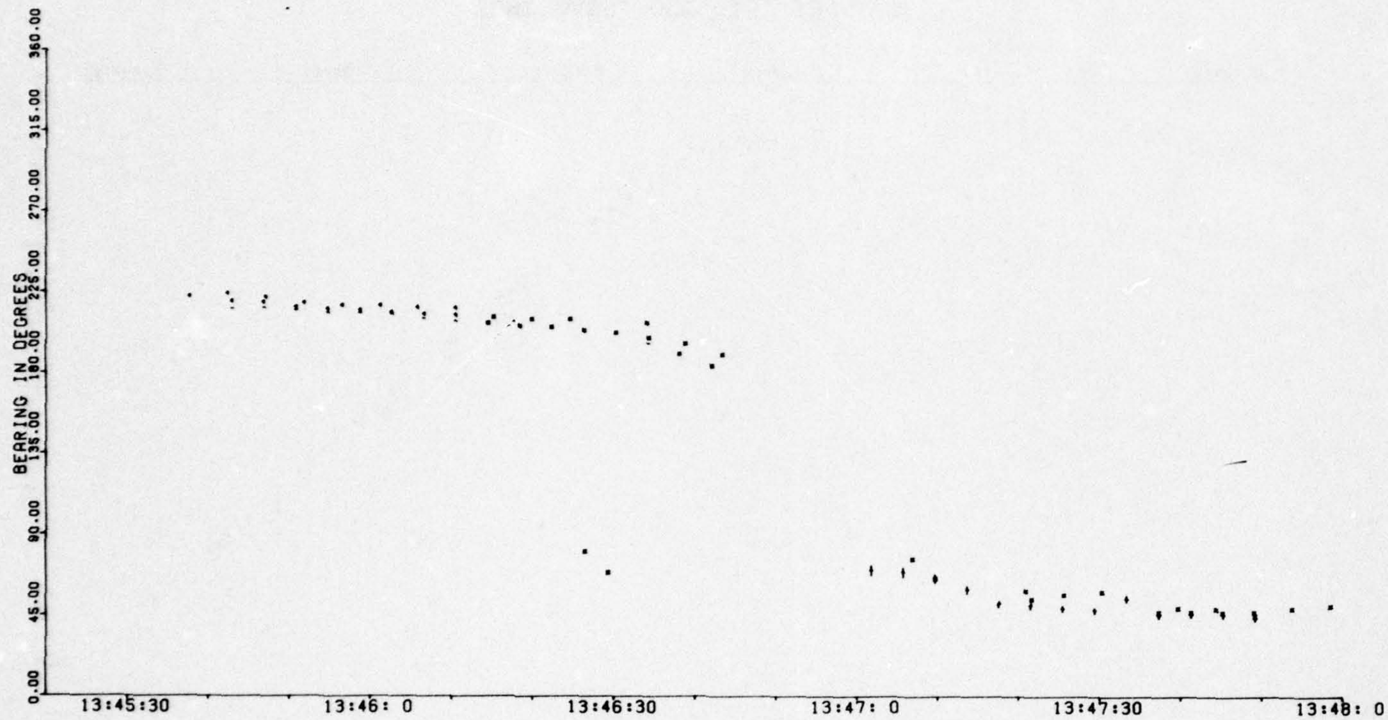
TEST DATE: OCT. 15, 1975
RUN #3 PATTERN #10 MODE I33

FIGURE 5.2-15



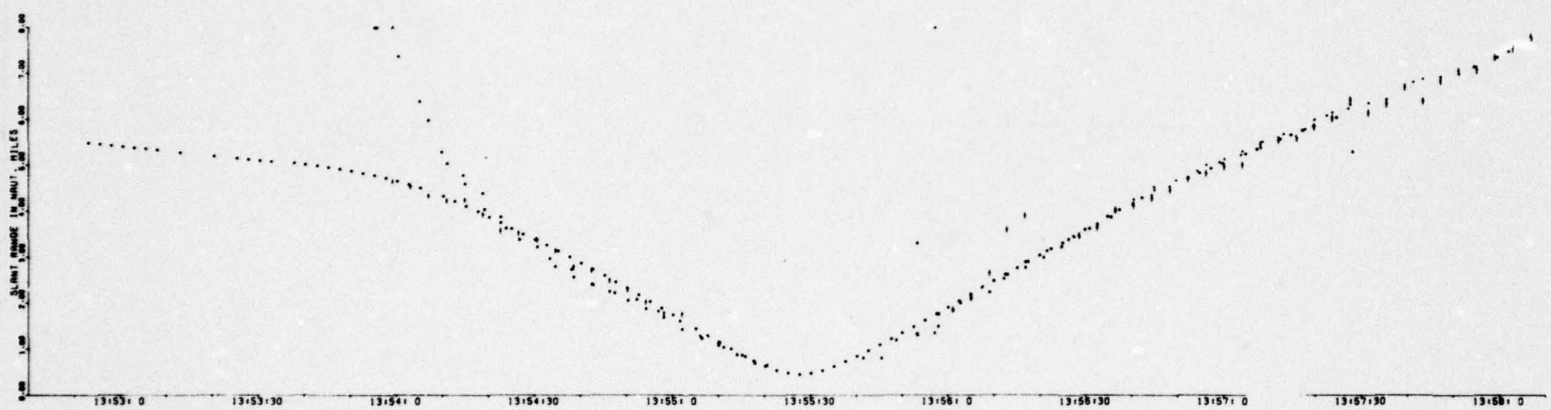
TEST DATE: OCT. 15, 1975
RUN #4 PATTERN #10 MODE I33

FIGURE 5.2-16



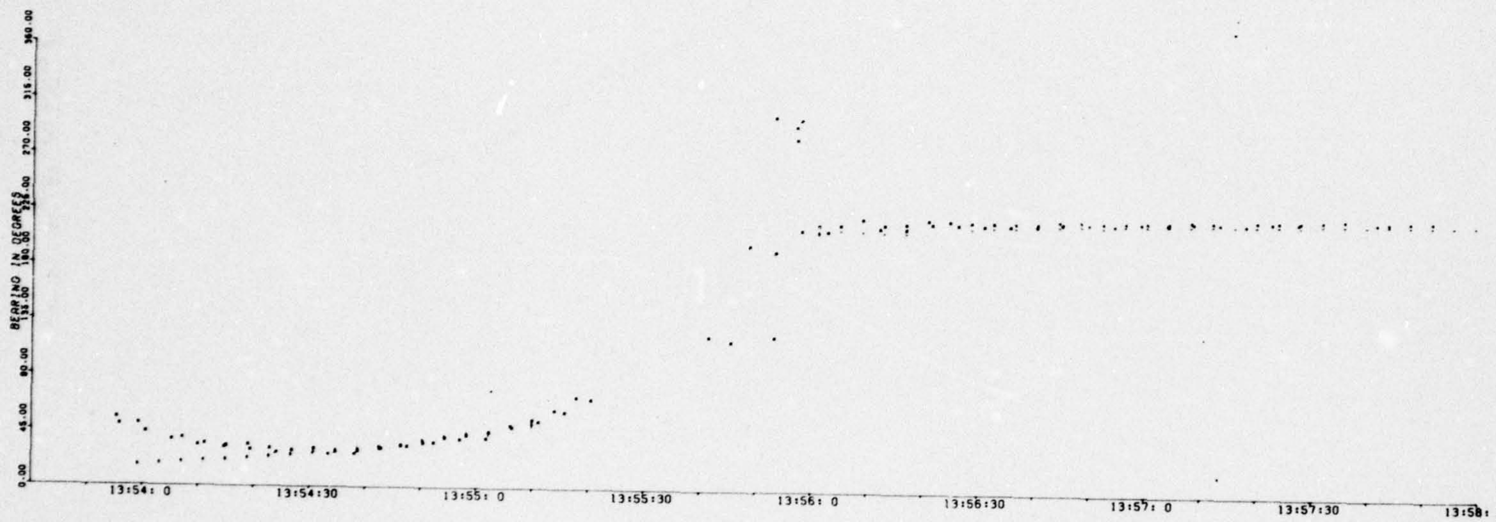
TEST DATE: OCT. 15, 1975
RUN #4 PATTERN #10 MODE I33

FIGURE 5.2-17



TEST DATE: OCT. 15, 1975
RUN #5 PATTERN #10 MODE I33

FIGURE 5.2-18



TEST DATE: OCT. 15, 1975
RUN #5 PATTERN #10 MODE I33

FIGURE 5.2-19

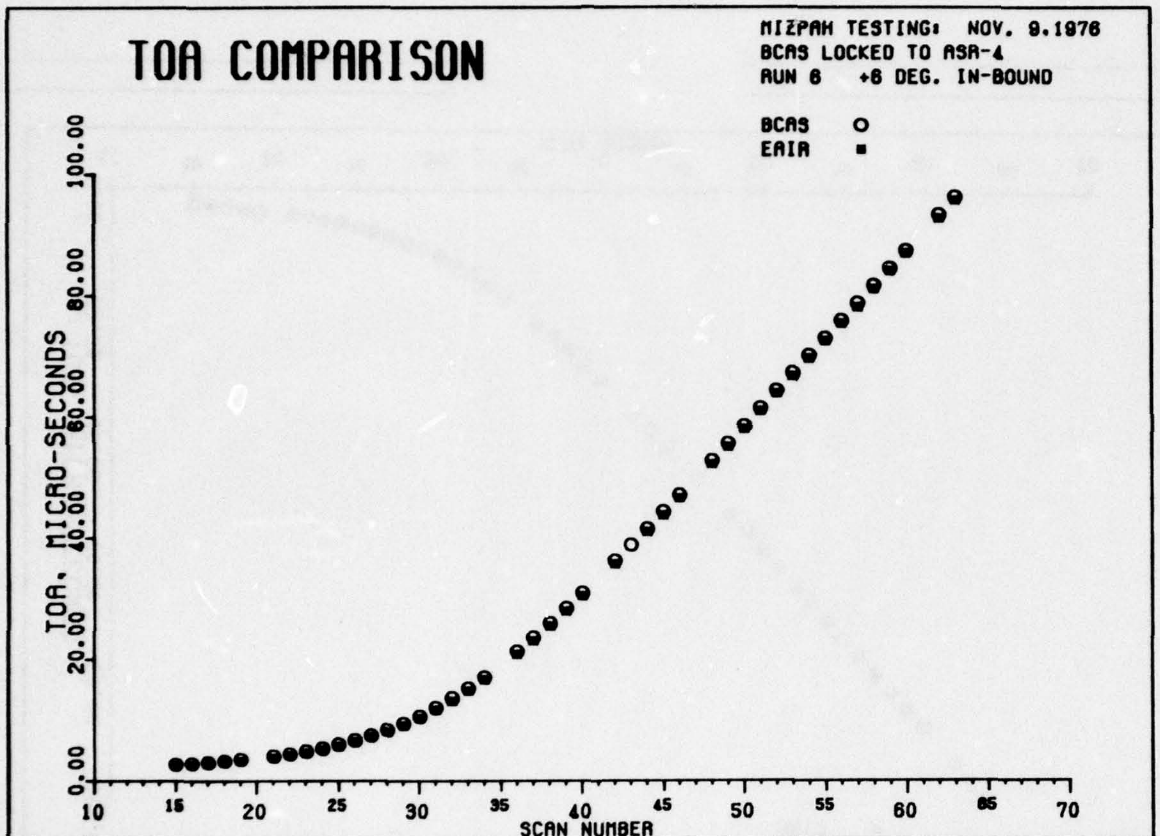
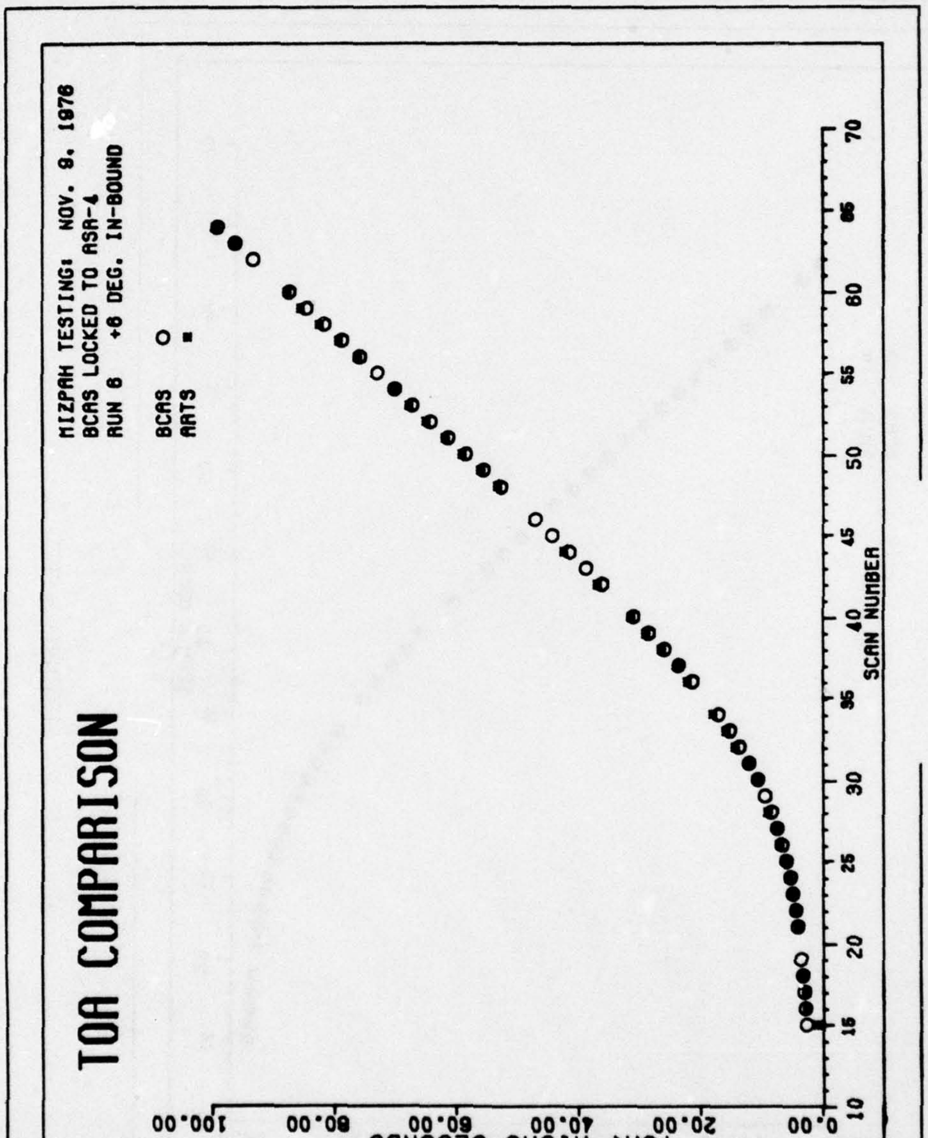

TOA COMPARISON
MIZPAH TESTING: NOV. 9.1976
BCAS LOCKED TO ASR-4
RUN 6 +8 DEG. IN-BOUND
BCAS
EAIR
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
10
15
20
25
30
35
40
45
50
55
60
65
70
SCAN NUMBER

FIGURE 5.3-1



TOA COMPARISON
MIZPAH TESTING: NOV. 9, 1978
BCAS LOCKED TO ASR-4
RUN 6 +8 DEG. IN-BOUND
BCAS
ARTS
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
10
15
20
25
30
35
40
45
50
55
60
65
70

FIGURE 5.3-2

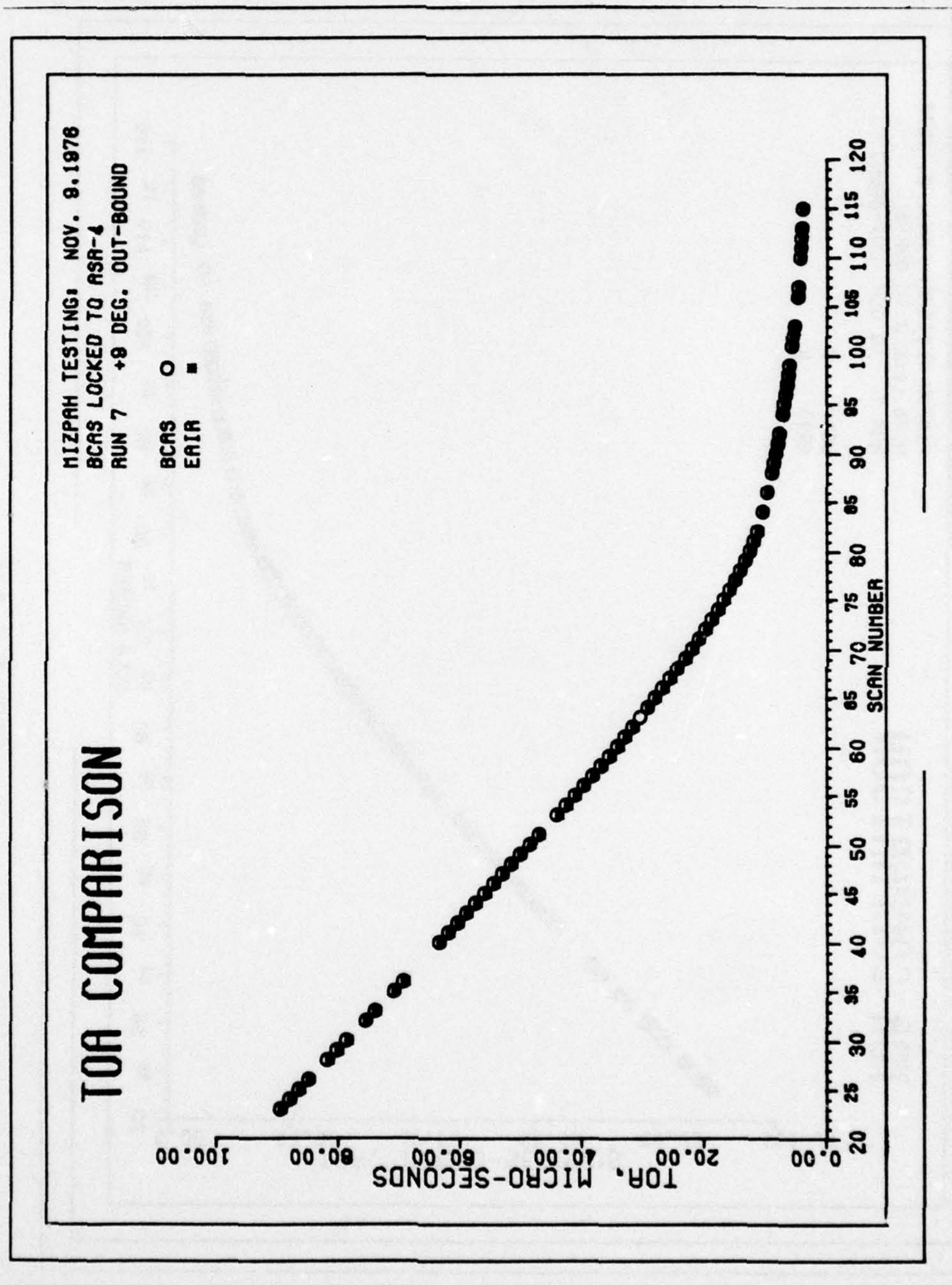

TOA COMPARISON
MIZPAH TESTING: NOV. 9.1978
BCAS LOCKED TO ASR-4
RUN 7 +8 DEG. OUT-BOUND
BCAS
EAIR
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.3-3

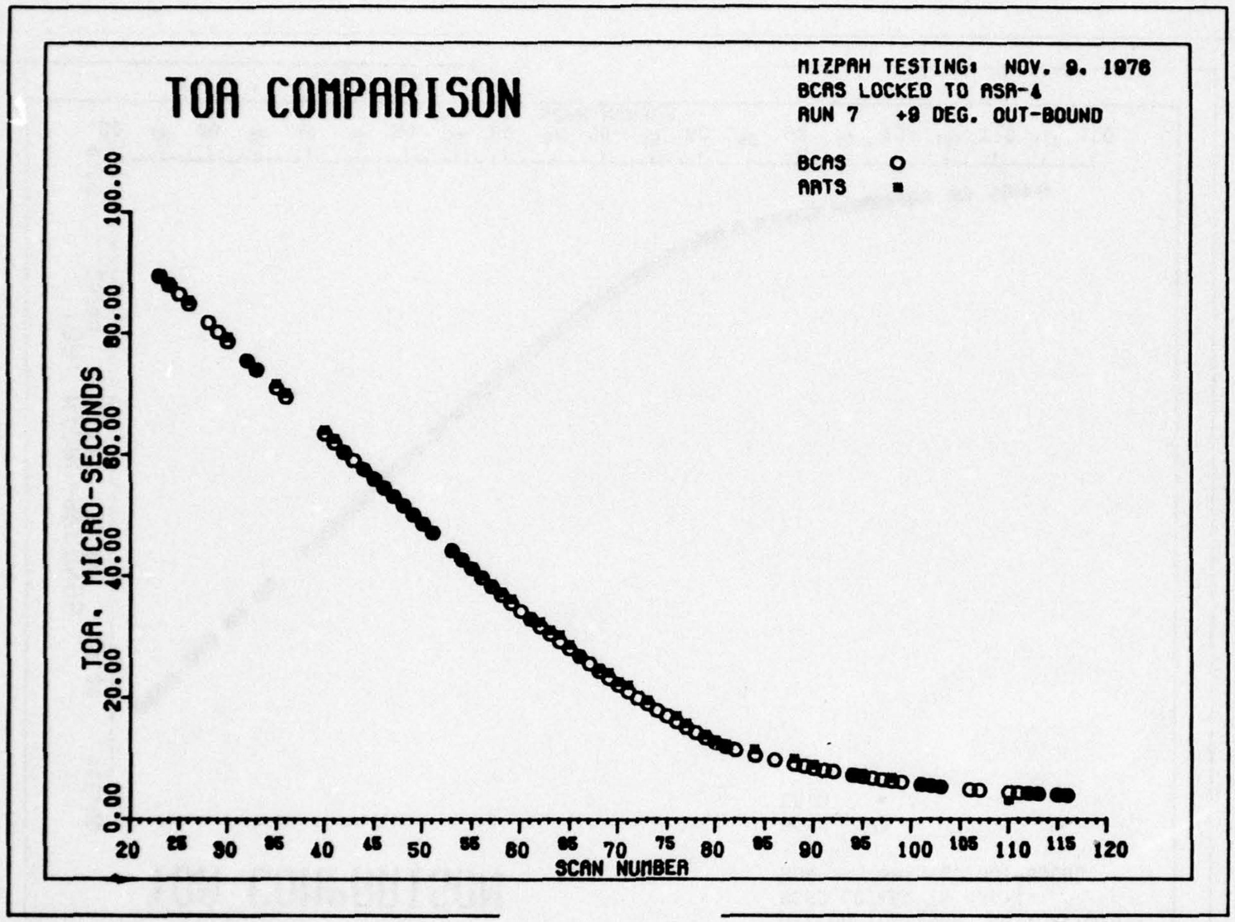

TOA COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 7 +9 DEG. OUT-BOUND
BCAS
ARTS
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
SCAN NUMBER

FIGURE 5.3-4

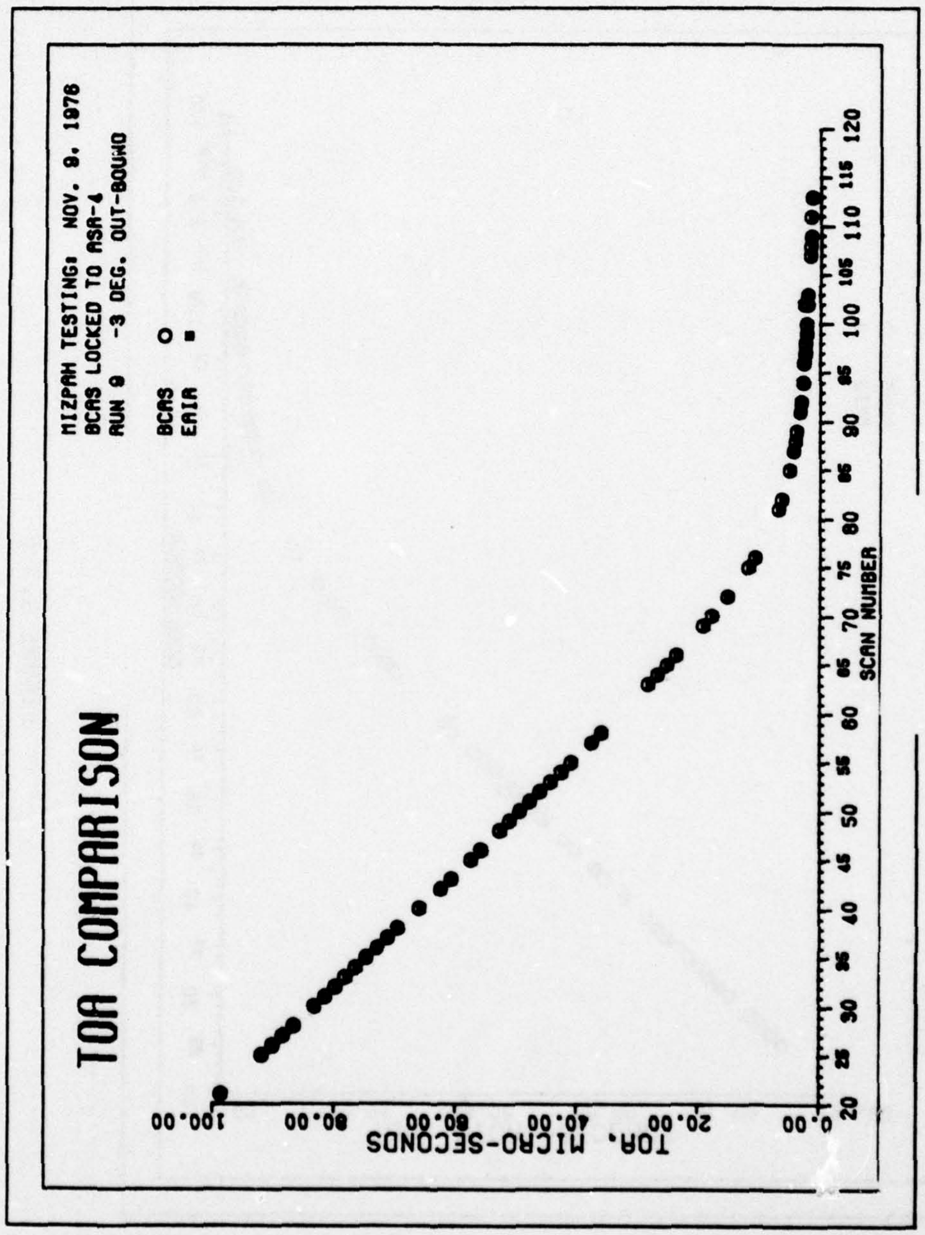
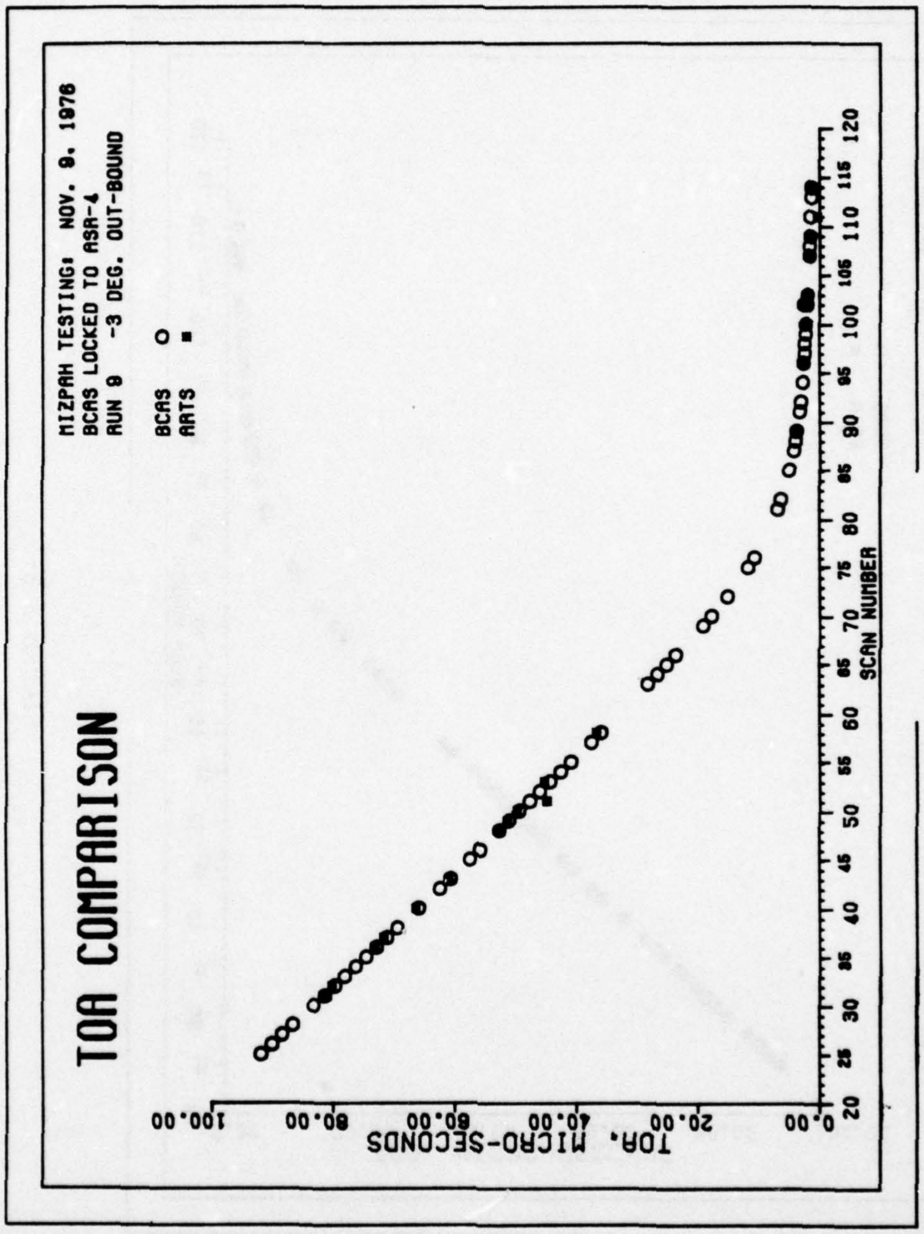

TOA COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 9 -3 DEG. OUT-BOUND
BCAS O
EAIR ■
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.3-5



TOA COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 9 -3 DEG. OUT-BOUND
BCAS
ARTS
TOA, MICRO-SECONDS
SCAN NUMBER

FIGURE 5.3-6

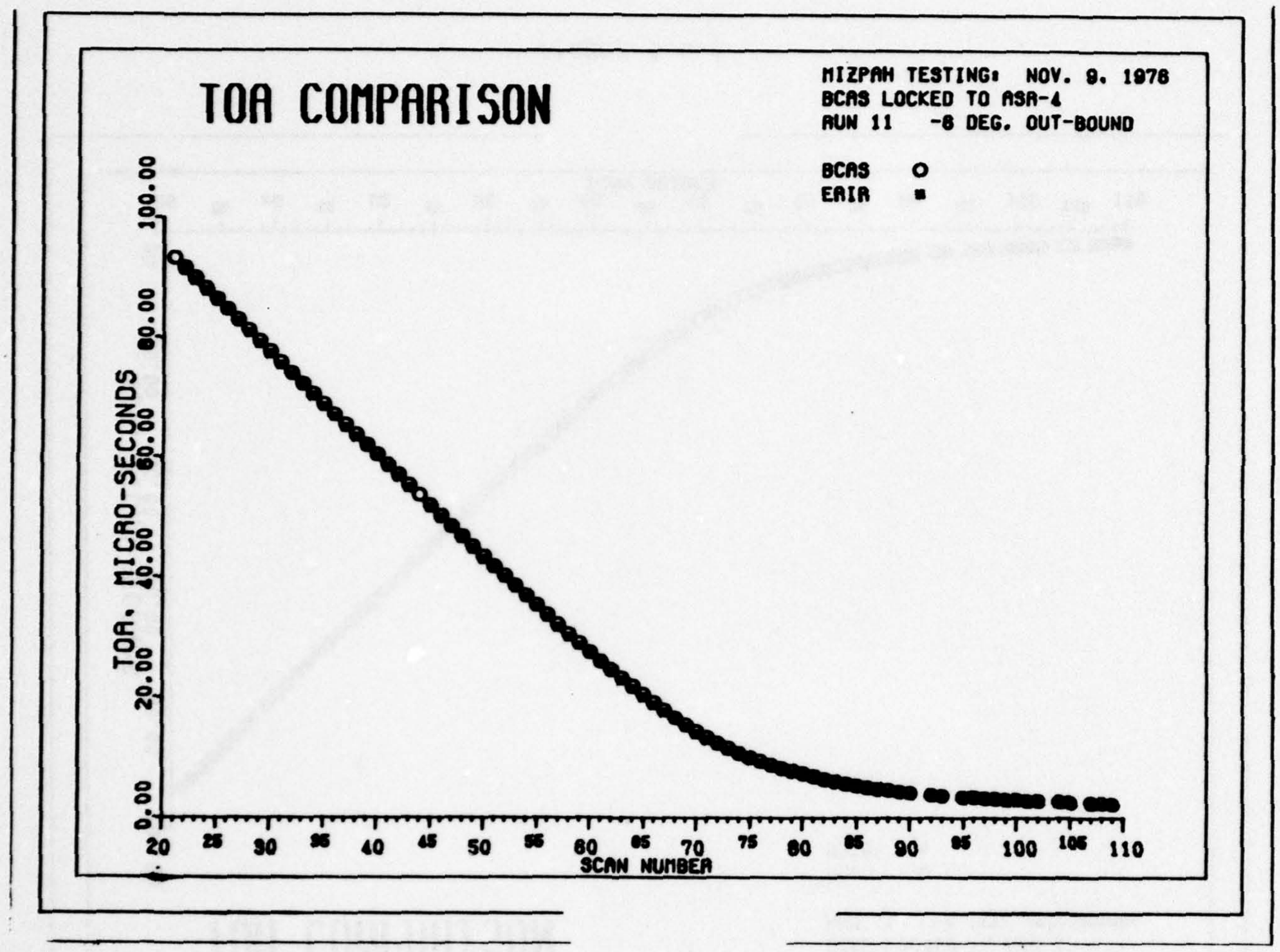

TOA COMPARISON
MIZPAH TESTING: NOV. 9. 1978
BCAS LOCKED TO ASR-4
RUN 11 -8 DEG. OUT-BOUND
BCAS
EAIR
TOA, MICRO-SECONDS
100.00
80.00
60.00
40.00
20.00
0.00
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
SCAN NUMBER

FIGURE 5.3-7

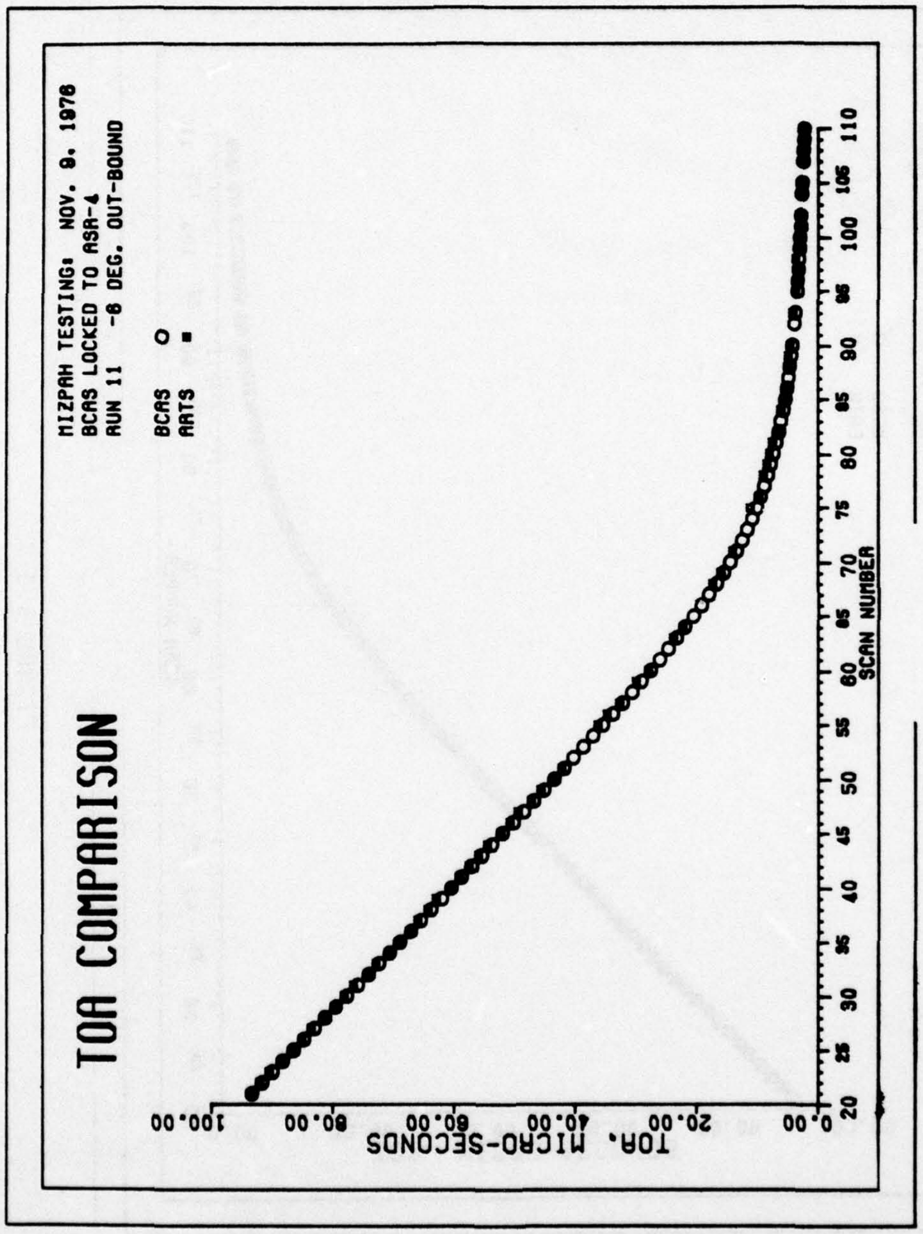

TOA COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 11 -6 DEG. OUT-BOUND
BCAS
ARTS
TOA, MICRO-SECONDS
0.00
20.00
40.00
60.00
80.00
100.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110

FIGURE 5.3-8

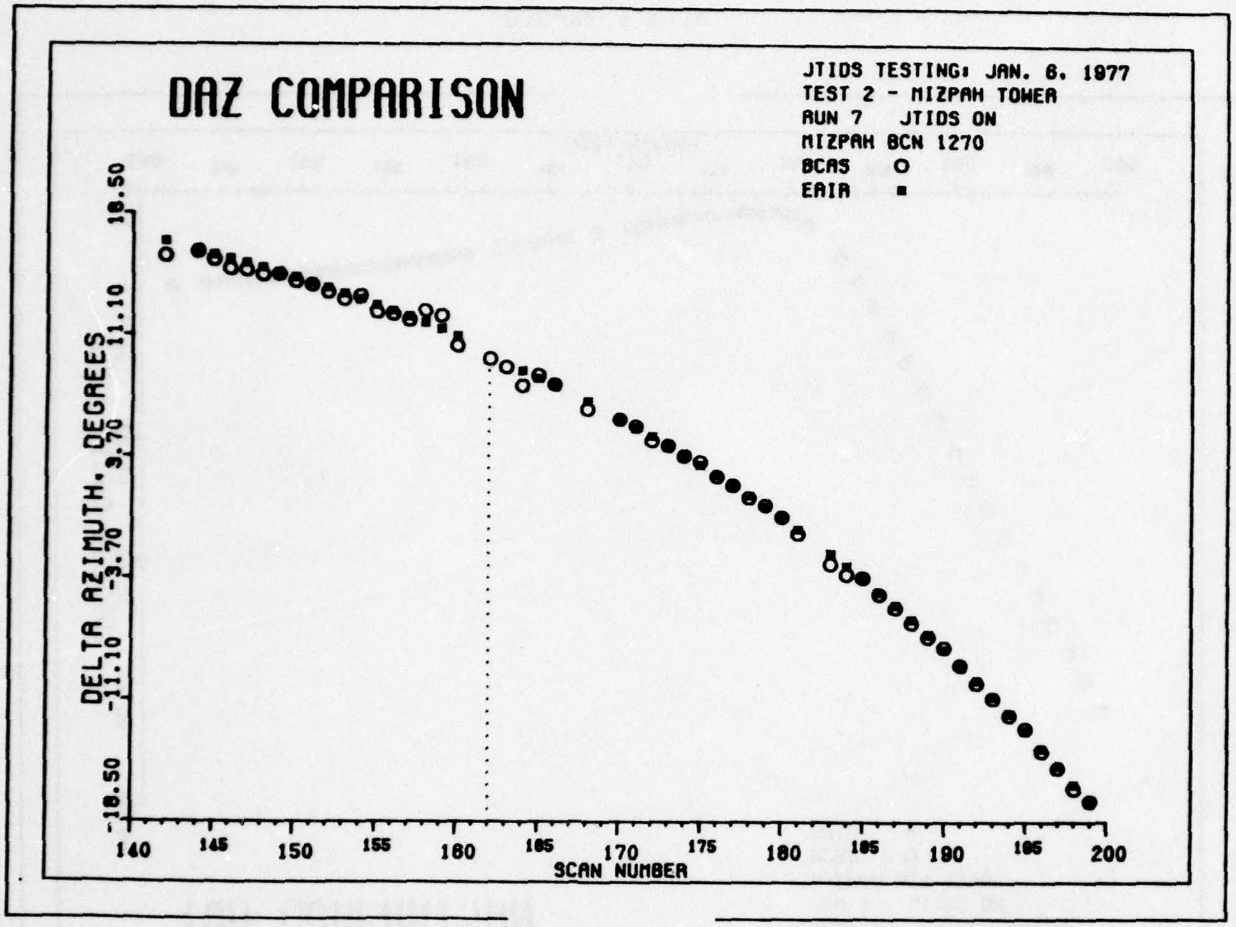

DAZ COMPARISON
JTIDS TESTING: JAN. 6, 1977
TEST 2 - MIZPAH TOWER
RUN 7 JTIDS ON
MIZPAH BCN 1270
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
140
145
150
155
160
165
170
175
180
185
190
195
200

FIGURE 5.3-9

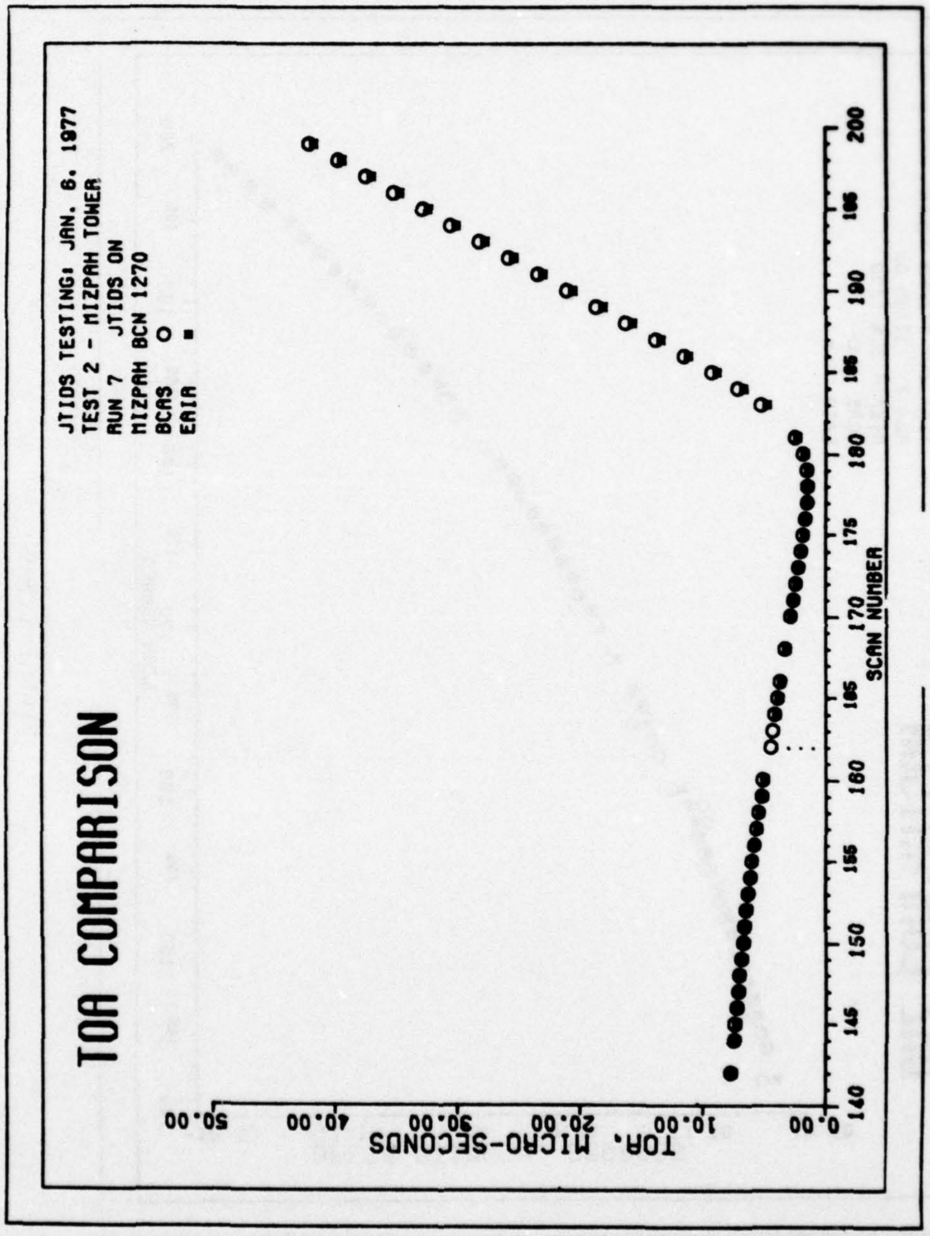

TOA COMPARISON
JTIDS TESTING: JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 7 JTIDS ON
MIZPAH BCN 1270
BCAS O
EAIA ■
TOA, MICRO-SECONDS
0.00
10.00
20.00
30.00
40.00
50.00
SCAN NUMBER
140
145
150
155
160
165
170
175
180
185
190
195
200

FIGURE 5.3-10

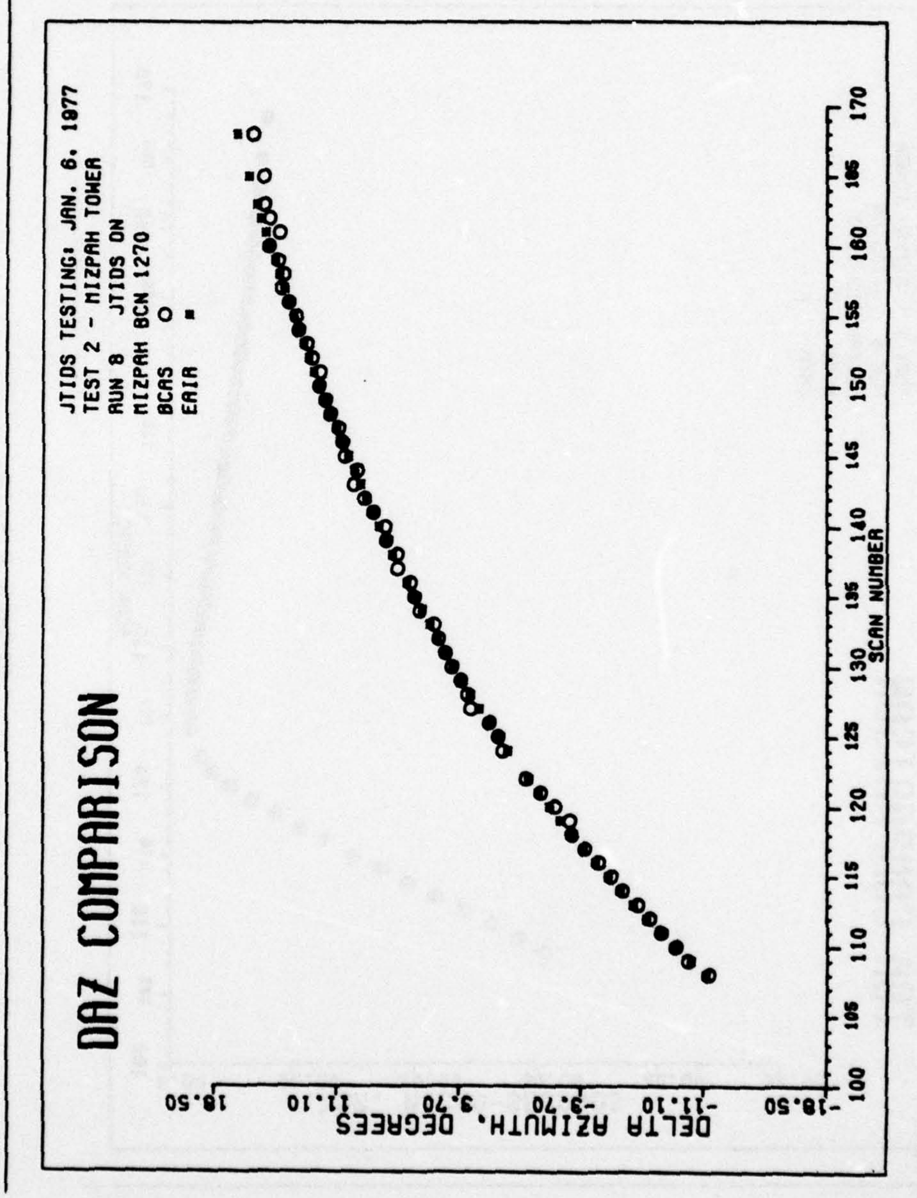

DAZ COMPARISON
JTIDS TESTING: JAN. 6, 1977
TEST 2 - MIZPAH TOWER
RUN 8 JTIDS ON
MIZPAH BCN 1270
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
SCAN NUMBER

FIGURE 5.3-11

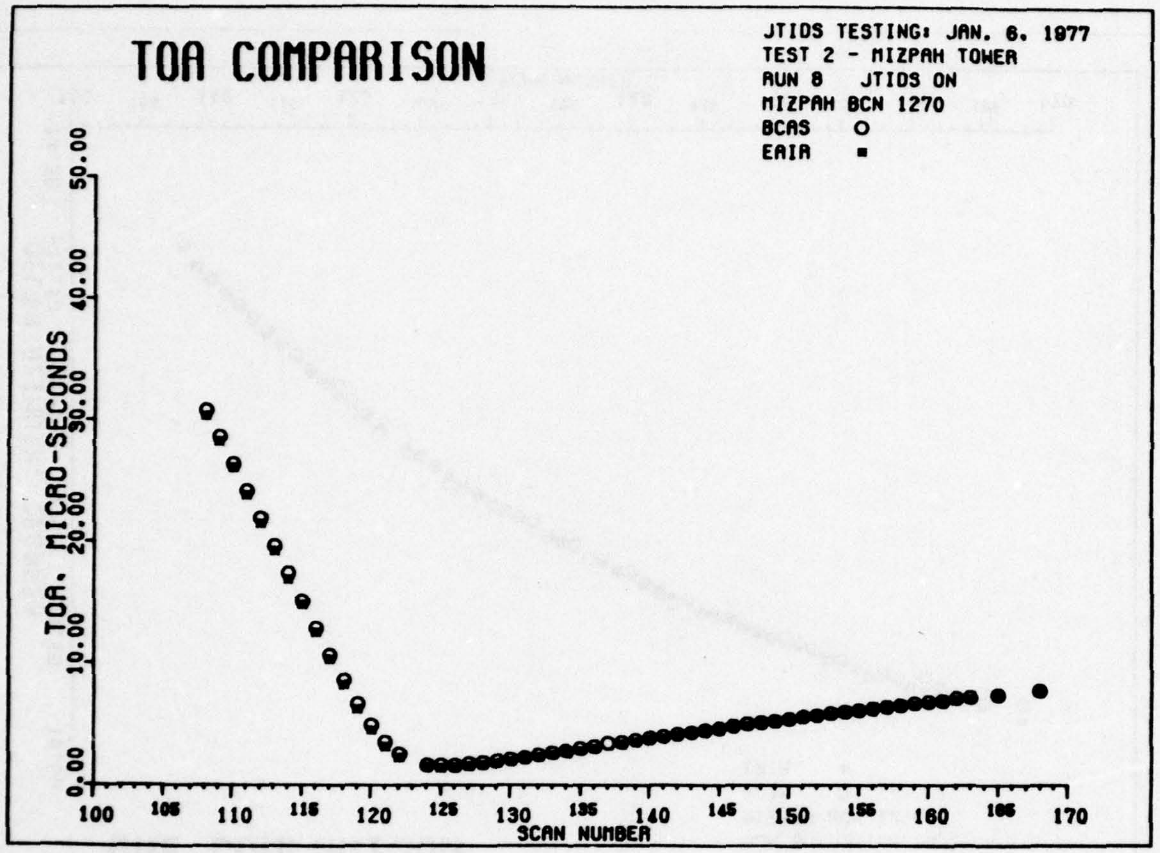

TOA COMPARISON
JTIDS TESTING: JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 8 JTIDS ON
MIZPAH BCN 1270
BCAS
EAIR
TOA, MICRO-SECONDS
0.00
10.00
20.00
30.00
40.00
50.00
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
SCAN NUMBER

FIGURE 5.3-12

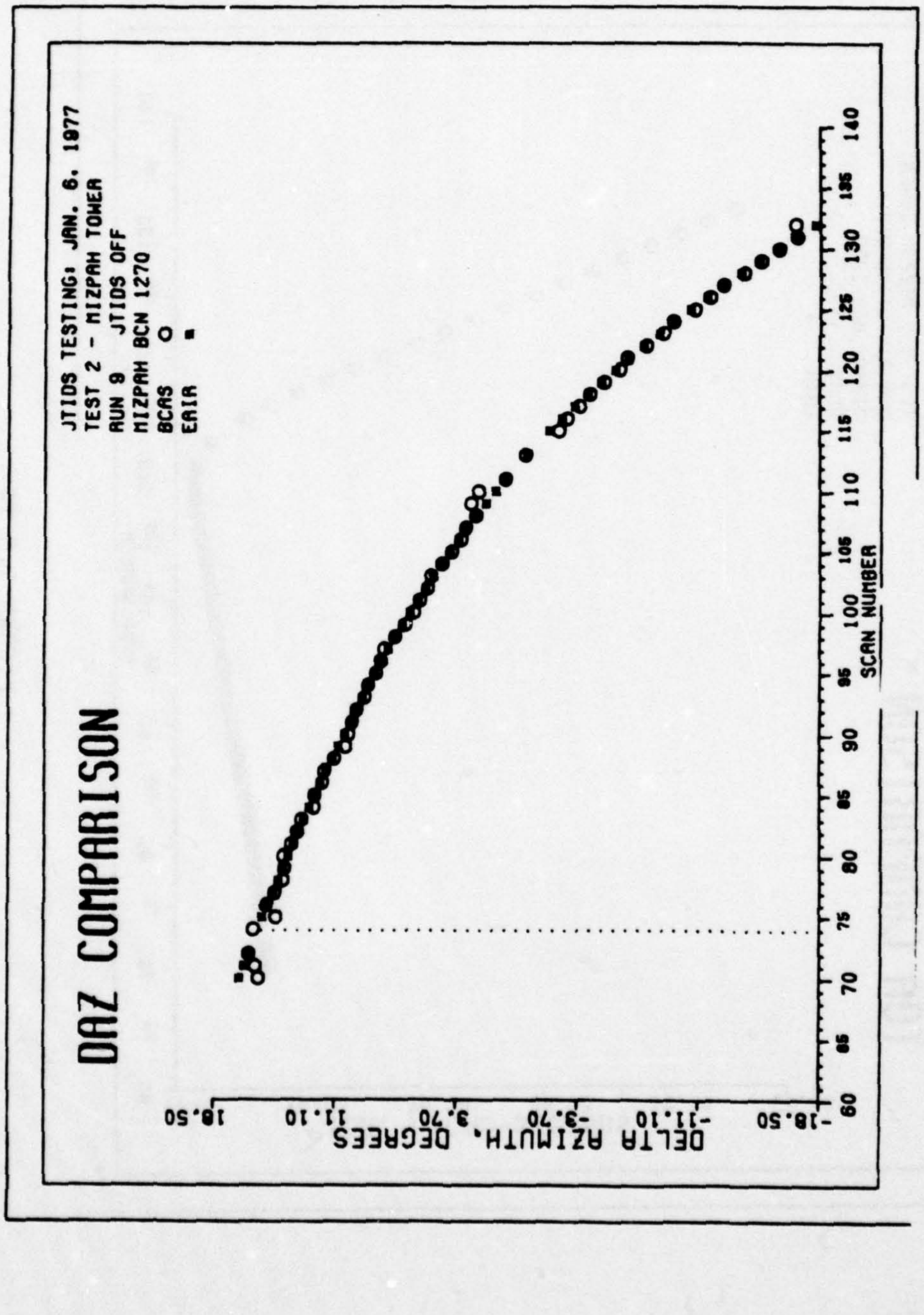

DAZ COMPARISON
JTIDS TESTING: JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 9 JTIDS OFF
MIZPAH BCN 1270
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140

FIGURE 5.3-13

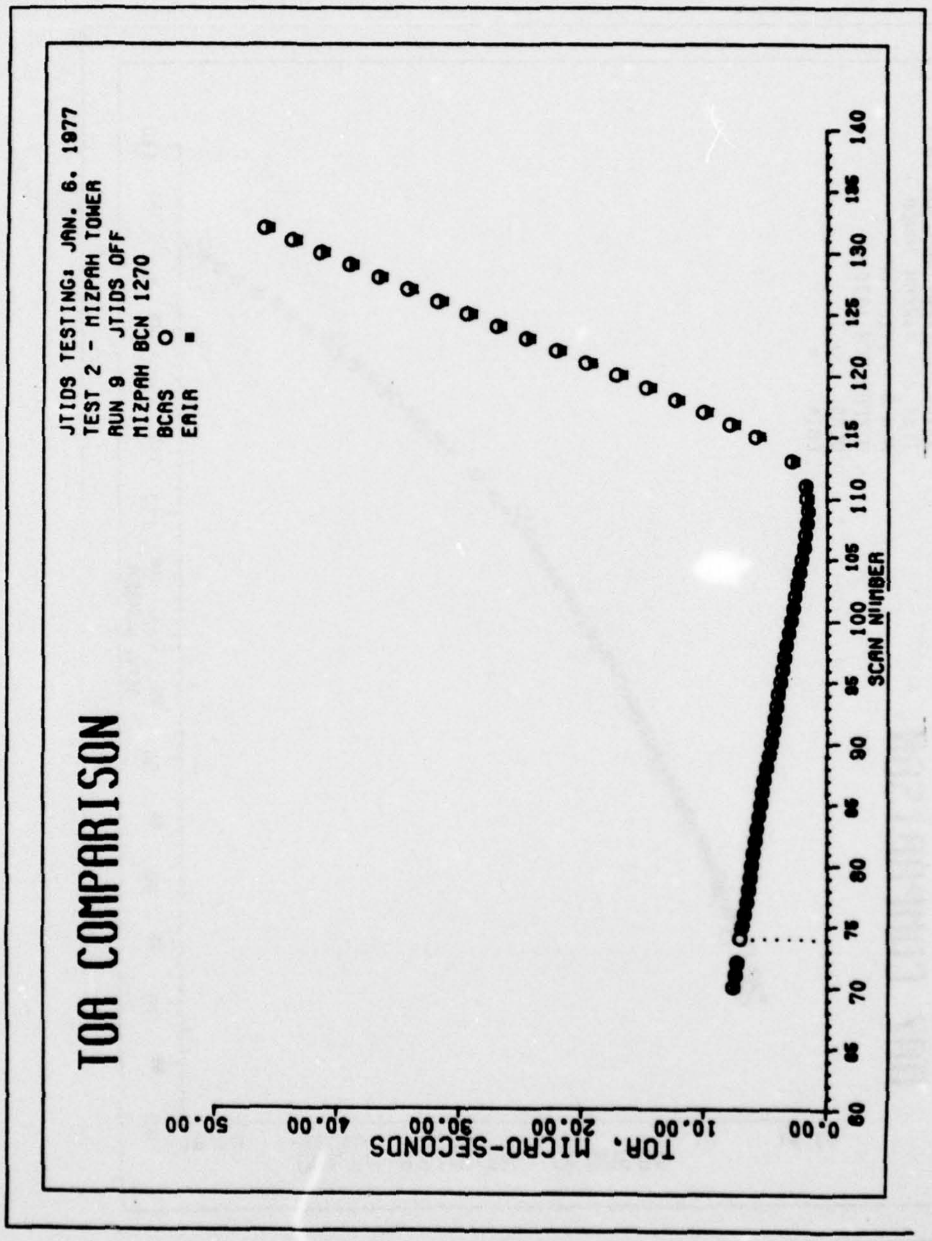
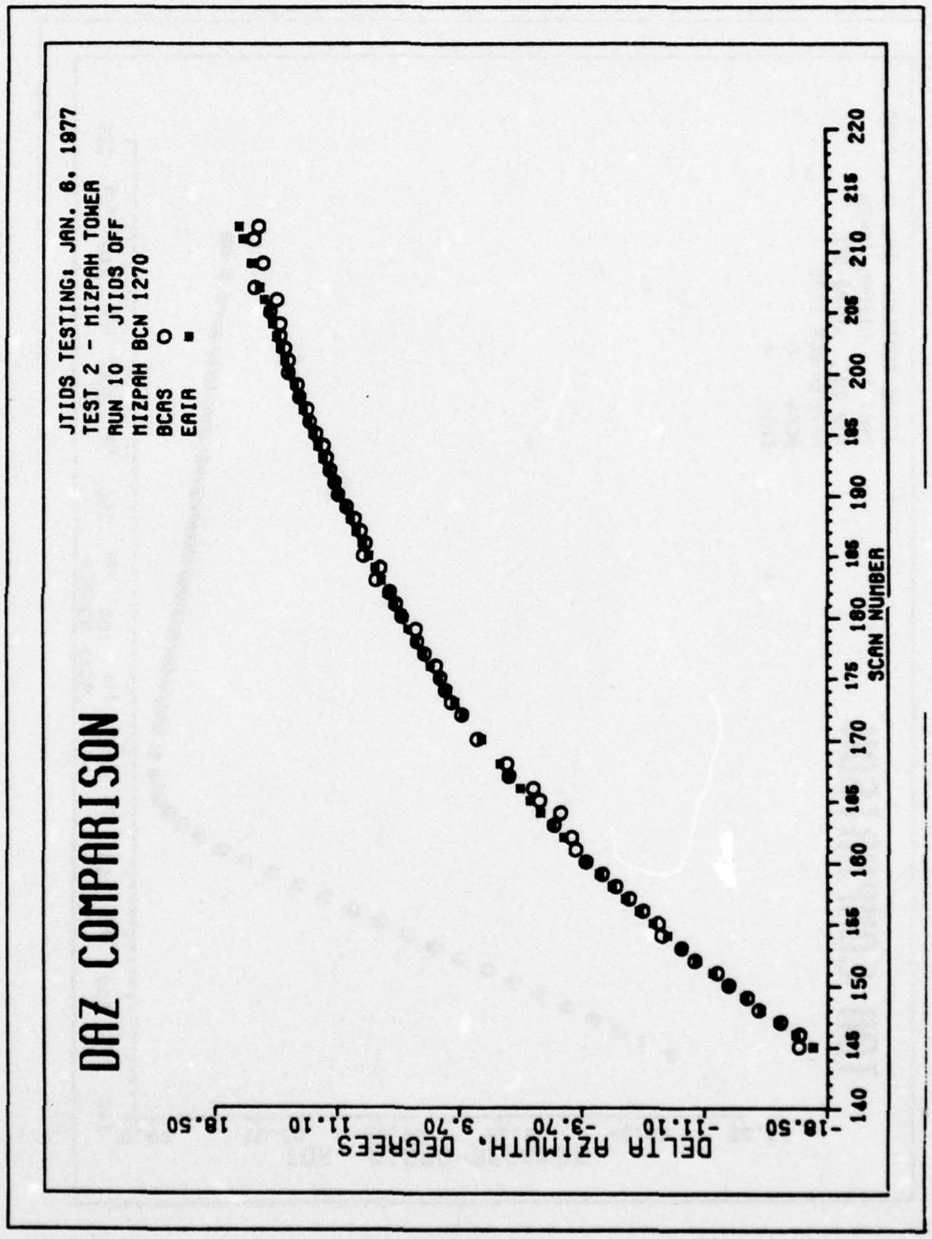

TOA COMPARISON
JTIDS TESTING: JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 9 JTIDS OFF
MIZPAH BCN 1270
BCAS O
EAIR ■
TOA, MICRO-SECONDS
0.00
10.00
20.00
30.00
40.00
50.00
SCAN NUMBER
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140

FIGURE 5.3-14



DAZ COMPARISON
JTIDS TESTING: JAN. 6, 1977
TEST 2 - MIZPAH TOWER
RUN 10 JTIDS OFF
MIZPAH BCN 1270
BCAS
EAIA
SCAN NUMBER
DELTA AZIMUTH, DEGREES

FIGURE 5.3-15

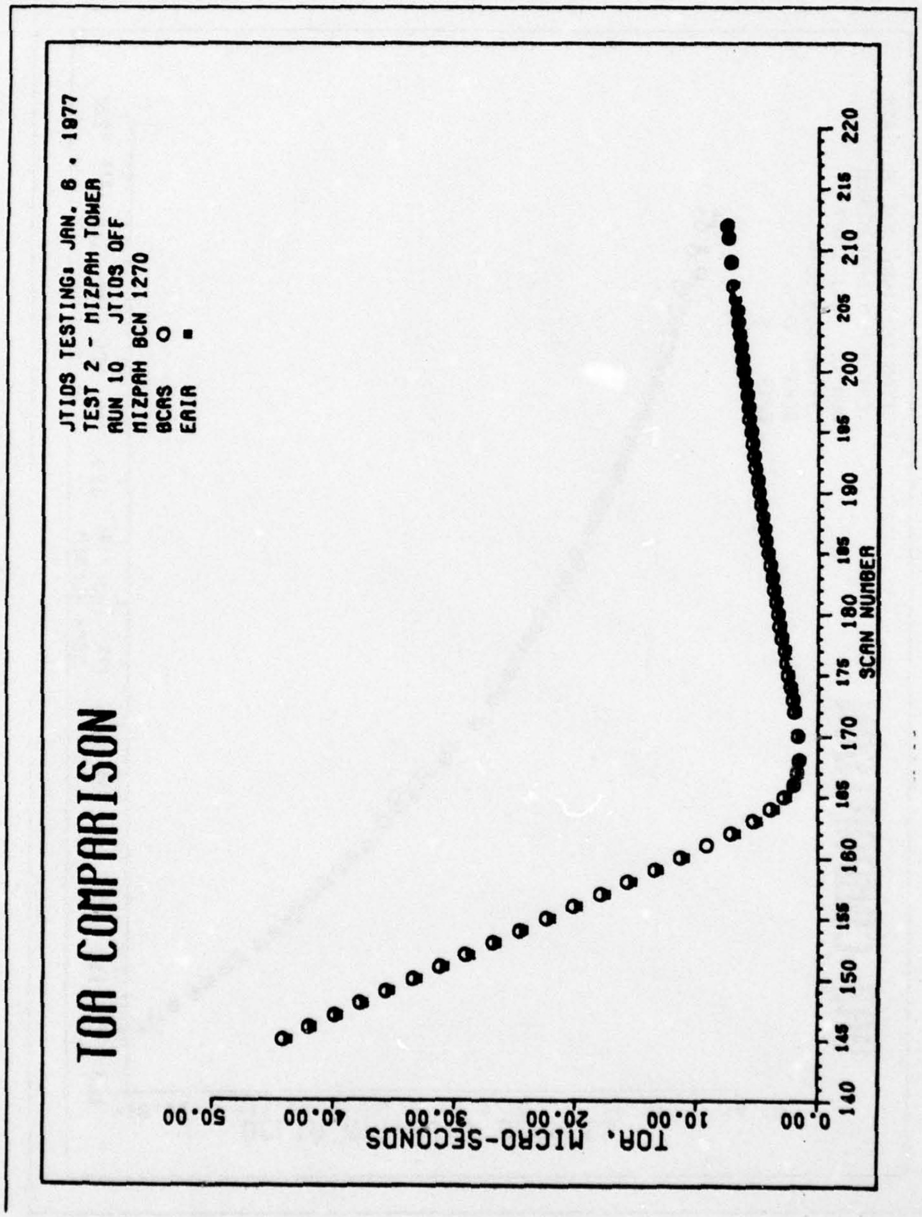

TOA COMPARISON
JTIDS TESTING: JAN. 6 , 1977
TEST 2 - MIZPAH TOWER
RUN 10   JTIDS OFF
MIZPAH BCN 1270
BCAS O
EAIR ■
TOA, MICRO-SECONDS
0.00
10.00
20.00
30.00
40.00
50.00
SCAN NUMBER
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220

FIGURE 5.3-16

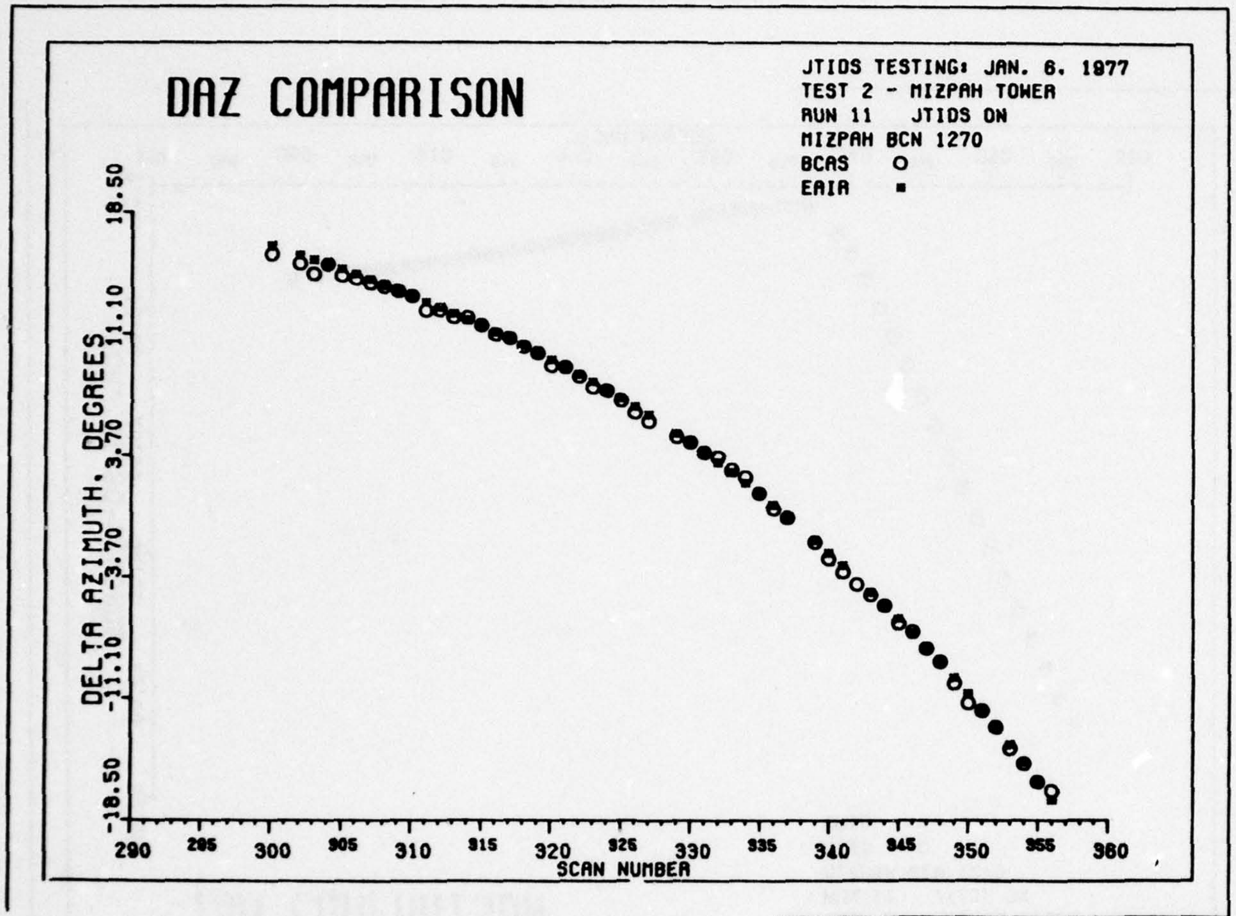

DAZ COMPARISON
JTIDS TESTING: JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 11 JTIDS ON
MIZPAH BCN 1270
BCAS
EAIA
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
SCAN NUMBER

FIGURE 5.3-17

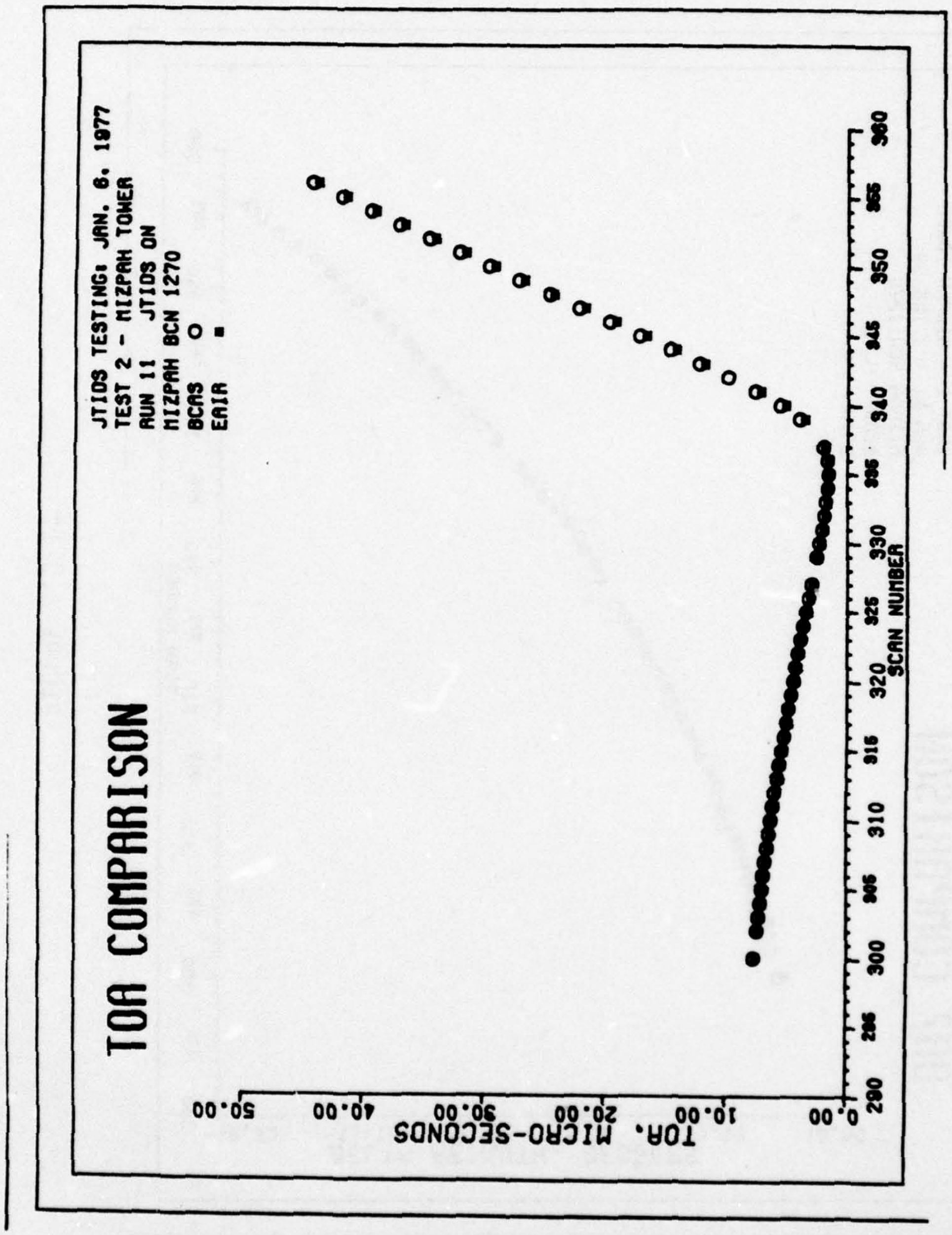

TOA COMPARISON
JTIDS TESTING: JAN. 6, 1977
TEST 2 - MIZPAH TOWER
RUN 11 JTIDS ON
MIZPAH BCN 1270
BCAS O
EAIR ■
TOA, MICRO-SECONDS
0.00
10.00
20.00
40.00
50.00
SCAN NUMBER
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360

FIGURE 5.3-18

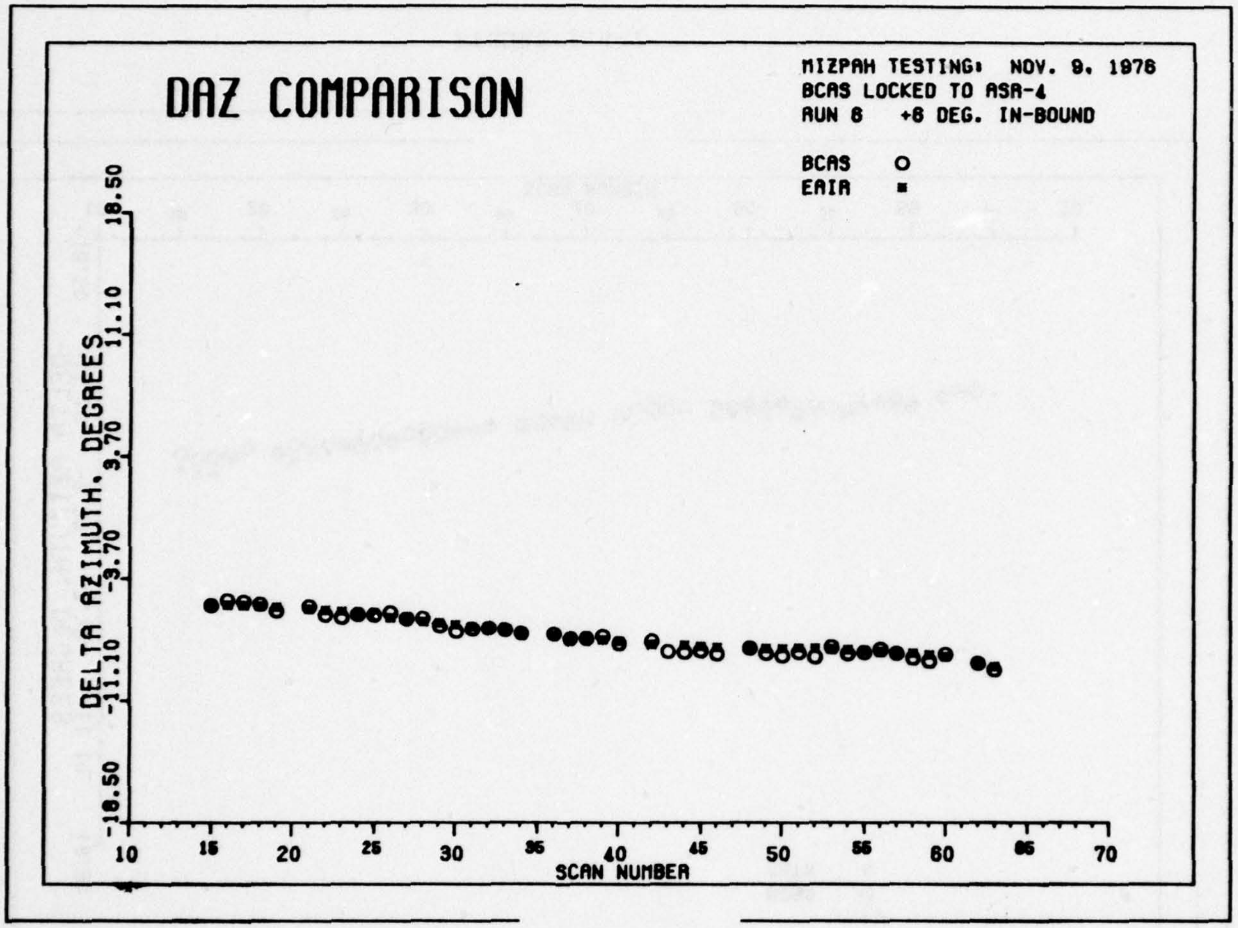

DAZ COMPARISON
MIZPAH TESTING: NOV. 9, 1976
BCAS LOCKED TO ASR-4
RUN 6 +8 DEG. IN-BOUND
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
10
15
20
25
30
35
40
45
50
55
60
65
70
SCAN NUMBER

FIGURE 5.4-1

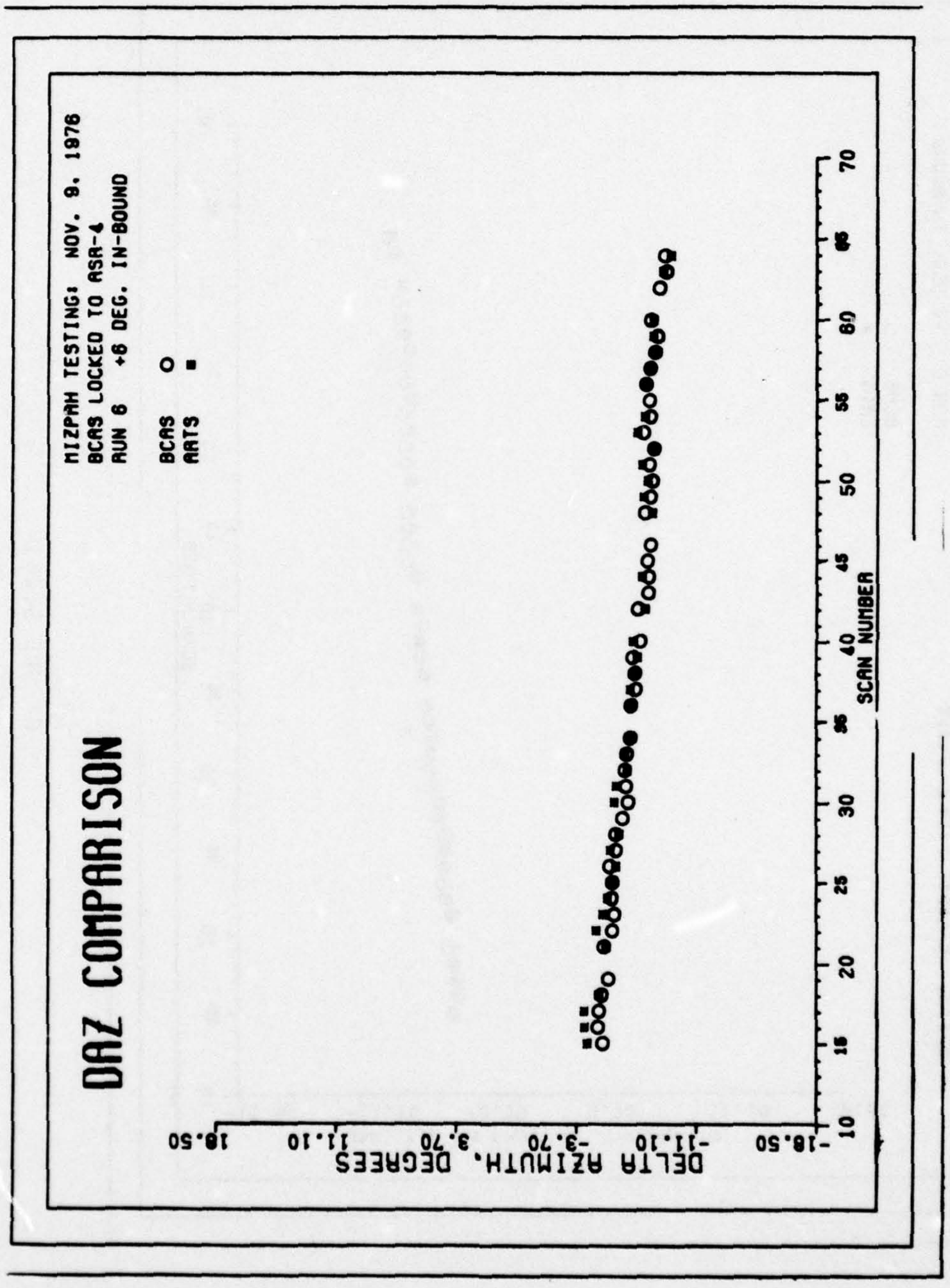

DAZ COMPARISON
MIZPAH TESTING: NOV. 9, 1976
BCAS LOCKED TO ASR-4
RUN 6 +6 DEG. IN-BOUND
BCAS
ARTS
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
10
15
20
25
30
35
40
45
50
55
60
65
70

FIGURE 5.4-2

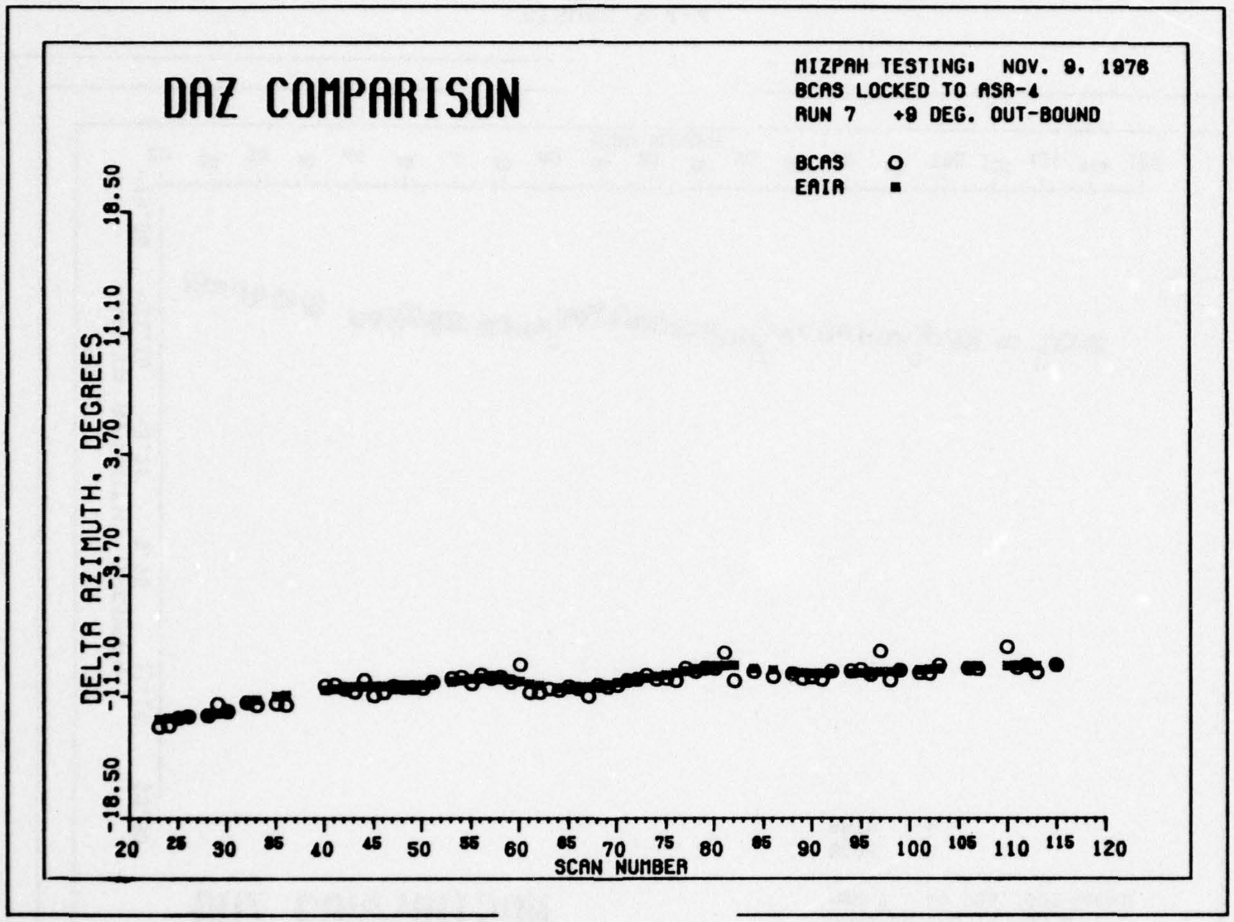

DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 7 +9 DEG. OUT-BOUND
BCAS
EAIR
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
SCAN NUMBER
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120

FIGURE 5.4-3

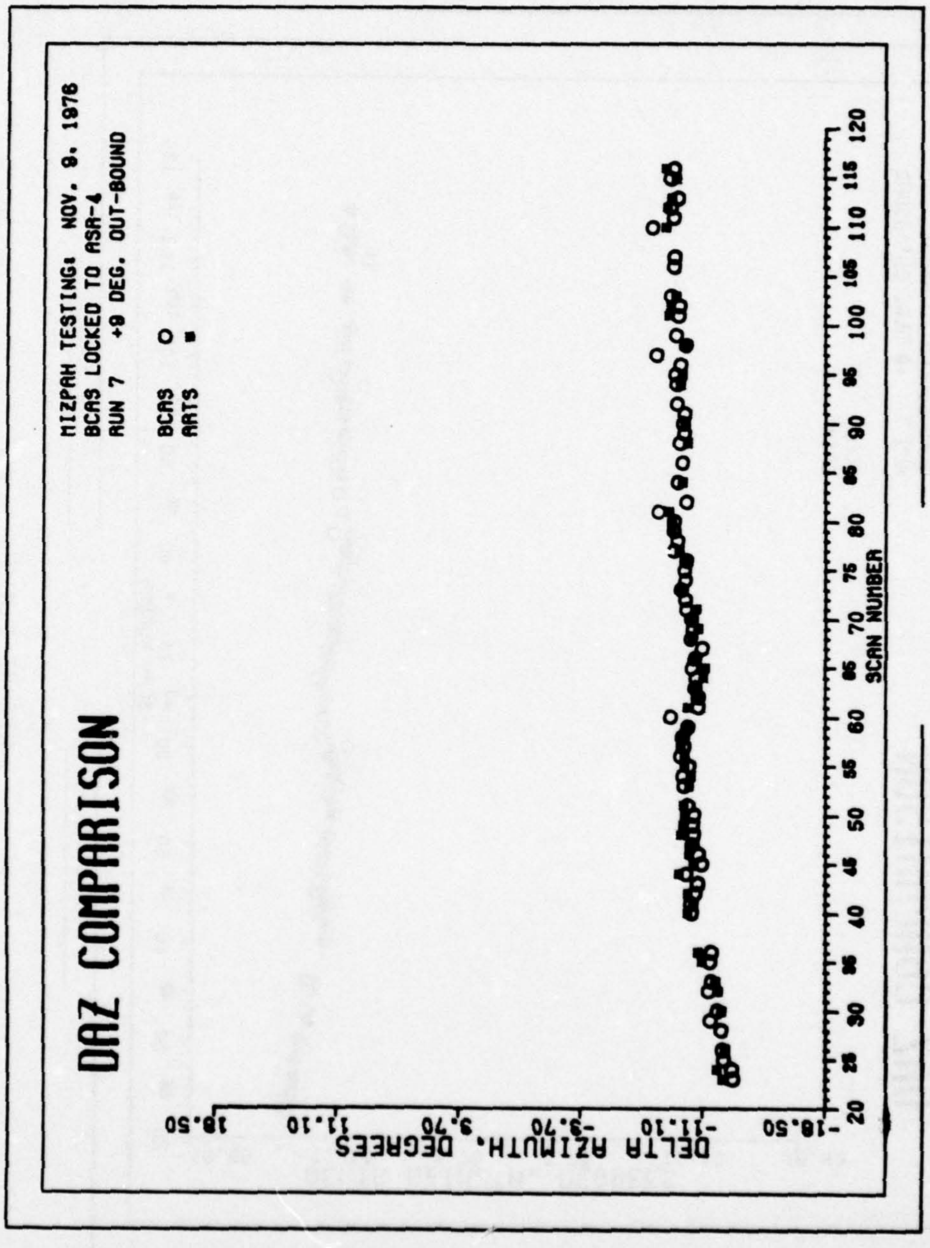
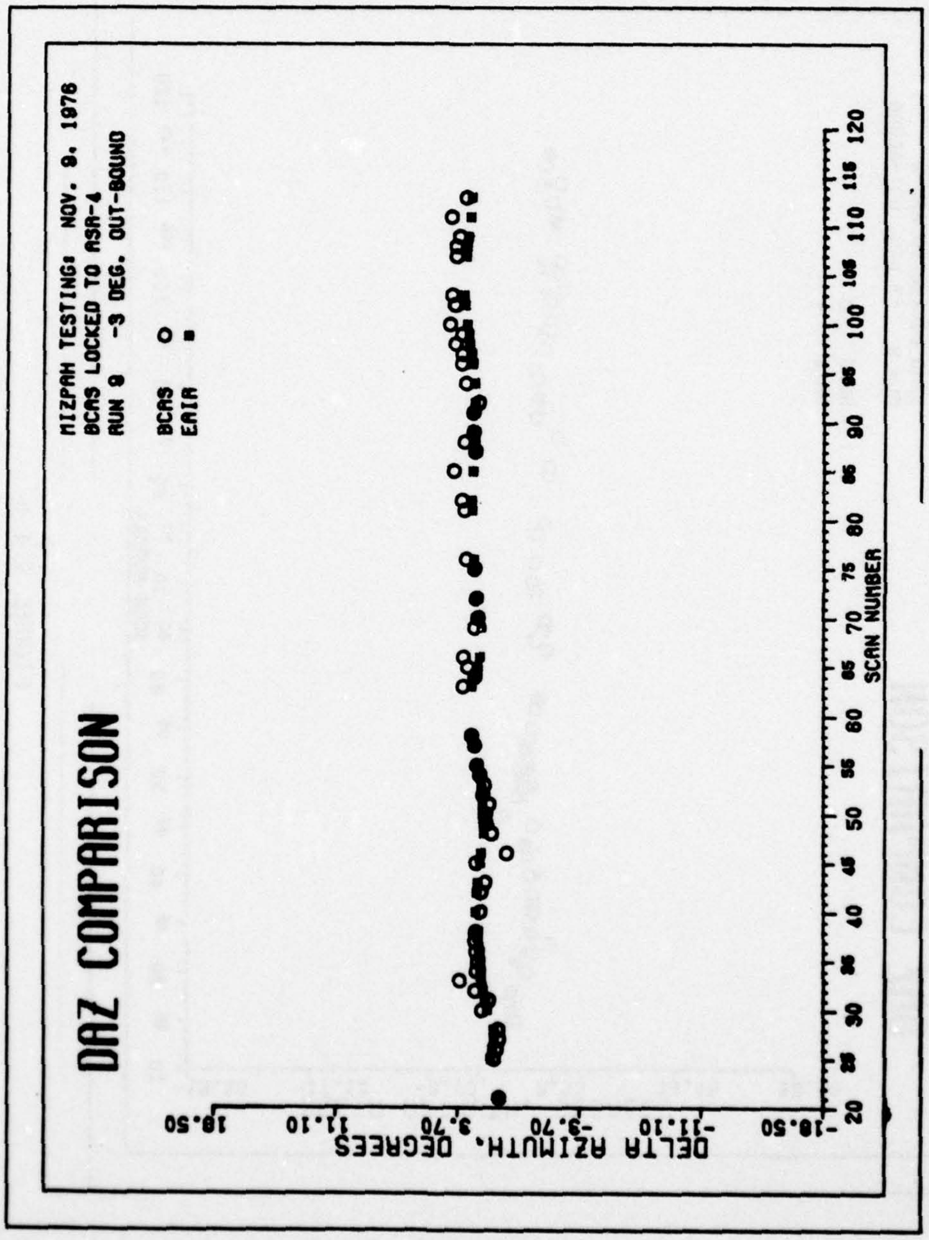
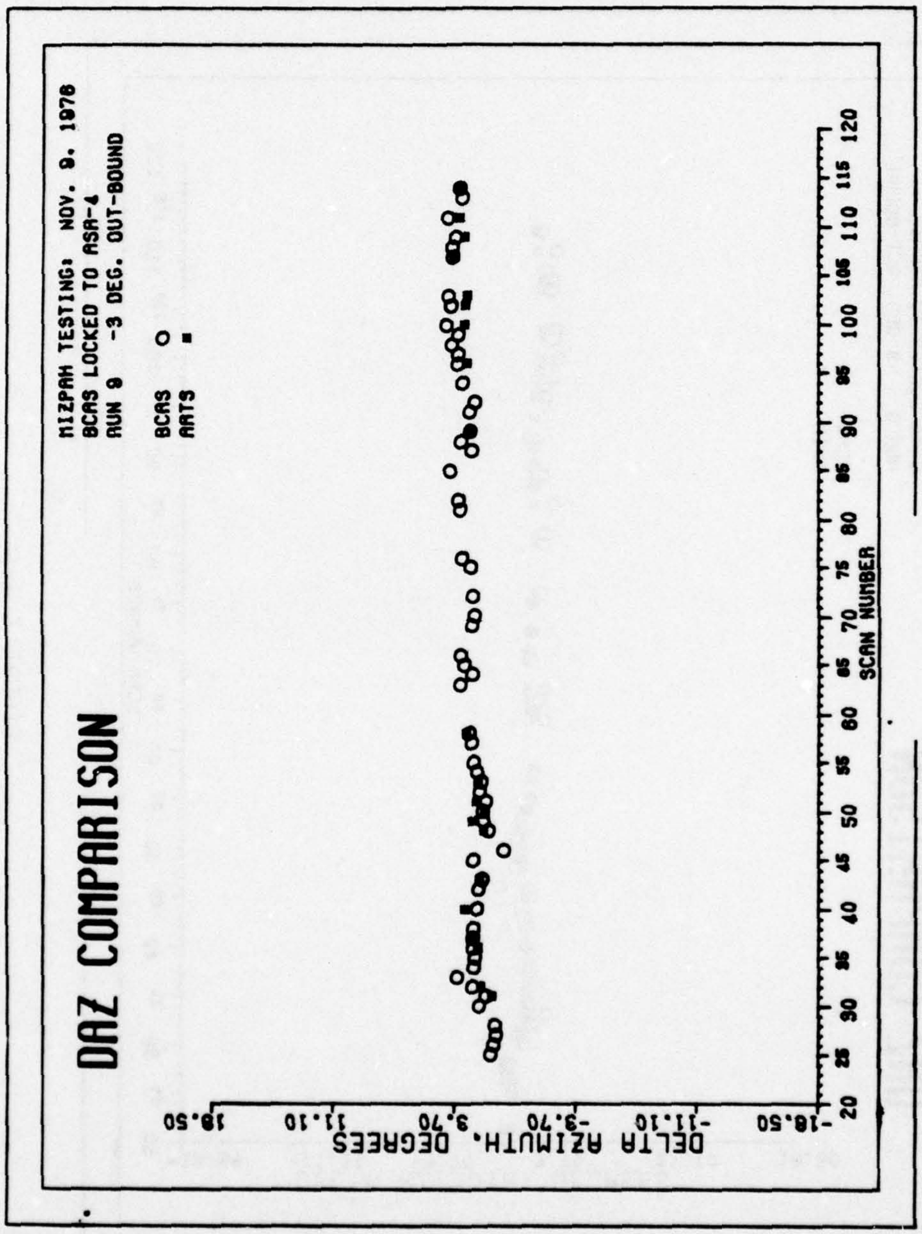

DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 7 +9 DEG. OUT-BOUND
BCAS O
ARTS ■
DELTA AZIMUTH, DEGREES
-18.50
-11.10
-3.70
3.70
11.10
18.50
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.4-4



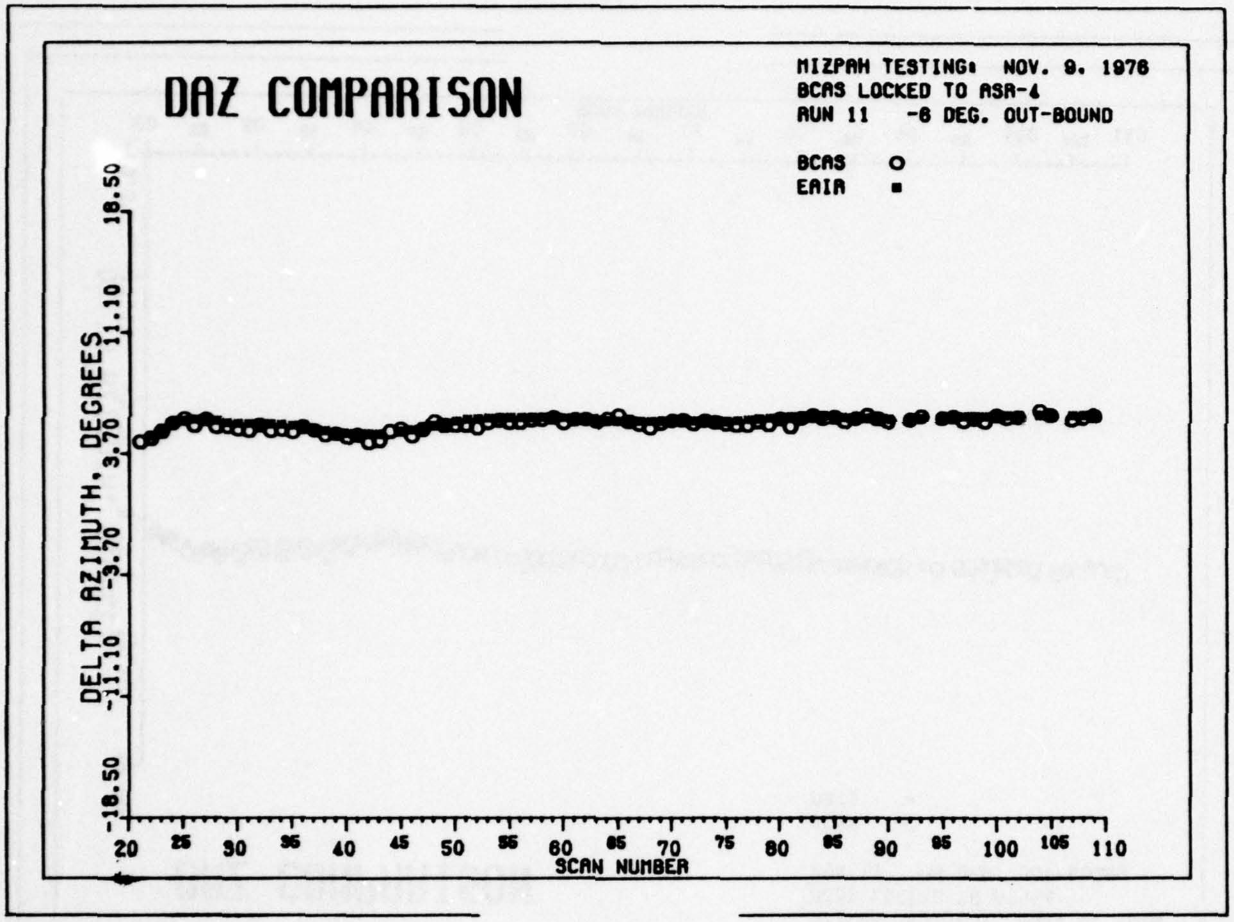
DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 9 -3 DEG. OUT-BOUND
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
SCAN NUMBER

FIGURE 5.4-5



DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1978
BCAS LOCKED TO ASA-4
RUN 9 -3 DEG. OUT-BOUND
BCAS
AATS
DELTA AZIMUTH, DEGREES
SCAN NUMBER

FIGURE 5.4-6



DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 11 -6 DEG. OUT-BOUND
BCAS O
EAIR ■
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
SCAN NUMBER

FIGURE 5.4-7

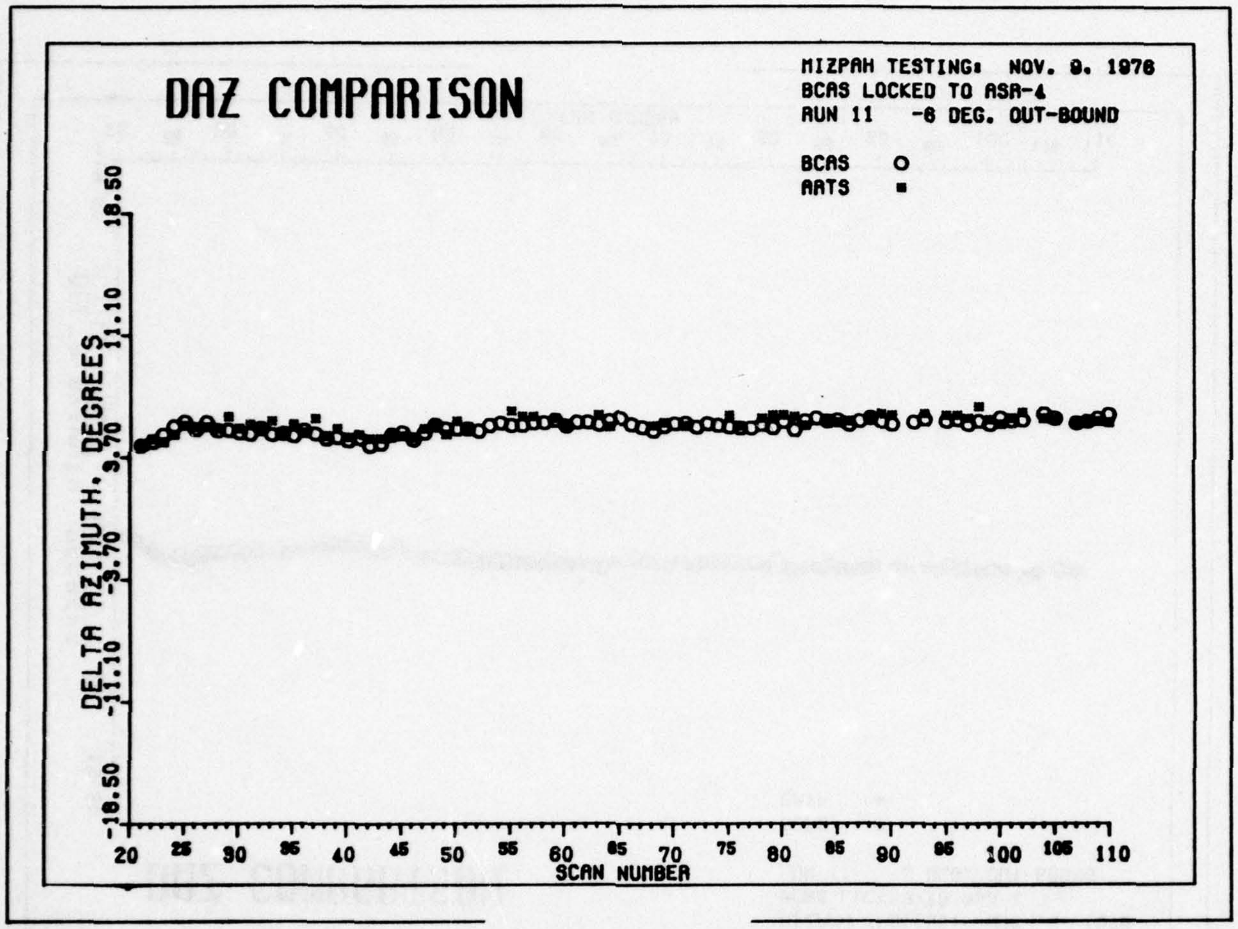
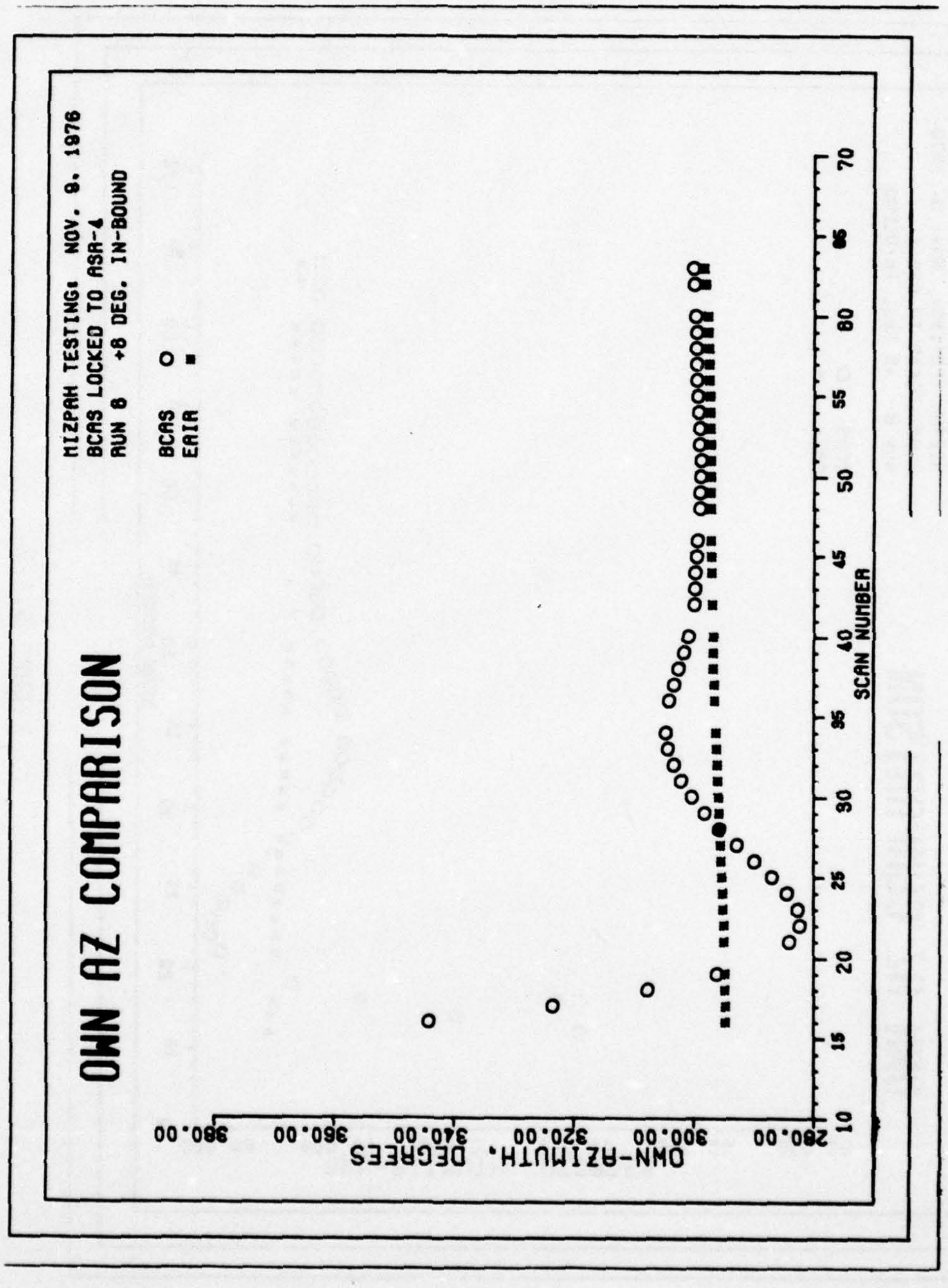

DAZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 11 -6 DEG. OUT-BOUND
BCAS
AATS
DELTA AZIMUTH, DEGREES
18.50
11.10
3.70
-3.70
-11.10
-18.50
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
SCAN NUMBER

FIGURE 5.4-8



OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 6 +8 DEG. IN-BOUND
BCAS
EAIA
OWN-AZIMUTH, DEGREES
280.00
300.00
320.00
340.00
360.00
380.00
SCAN NUMBER
10
15
20
25
30
35
40
45
50
55
60
65
70

FIGURE 5.5-1

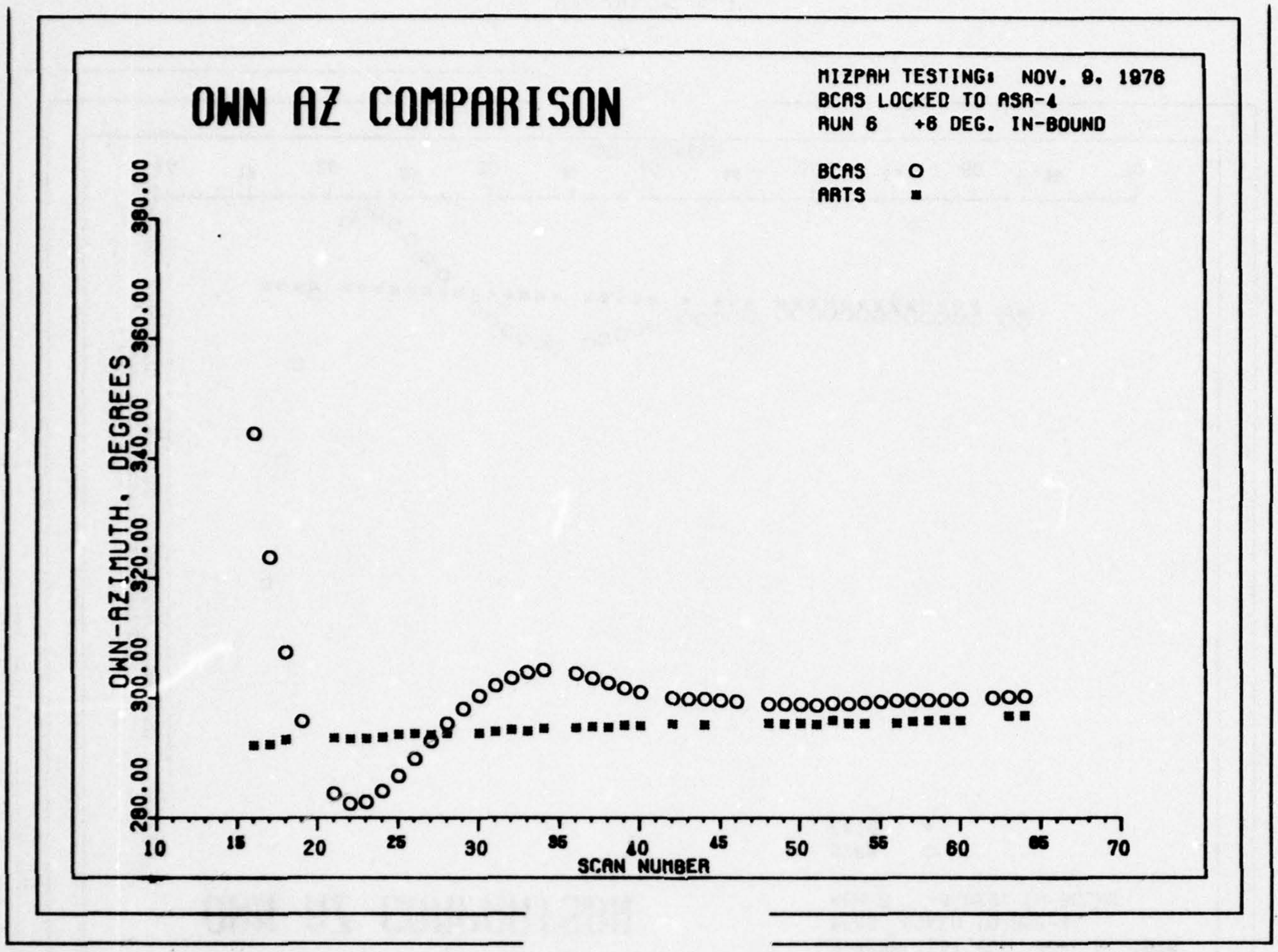

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 6 +8 DEG. IN-BOUND
BCAS O
ARTS ■
OWN-AZIMUTH, DEGREES
280.00
300.00
320.00
340.00
360.00
380.00
10
15
20
25
30
35
40
45
50
55
60
65
70
SCAN NUMBER

FIGURE 5.5-2

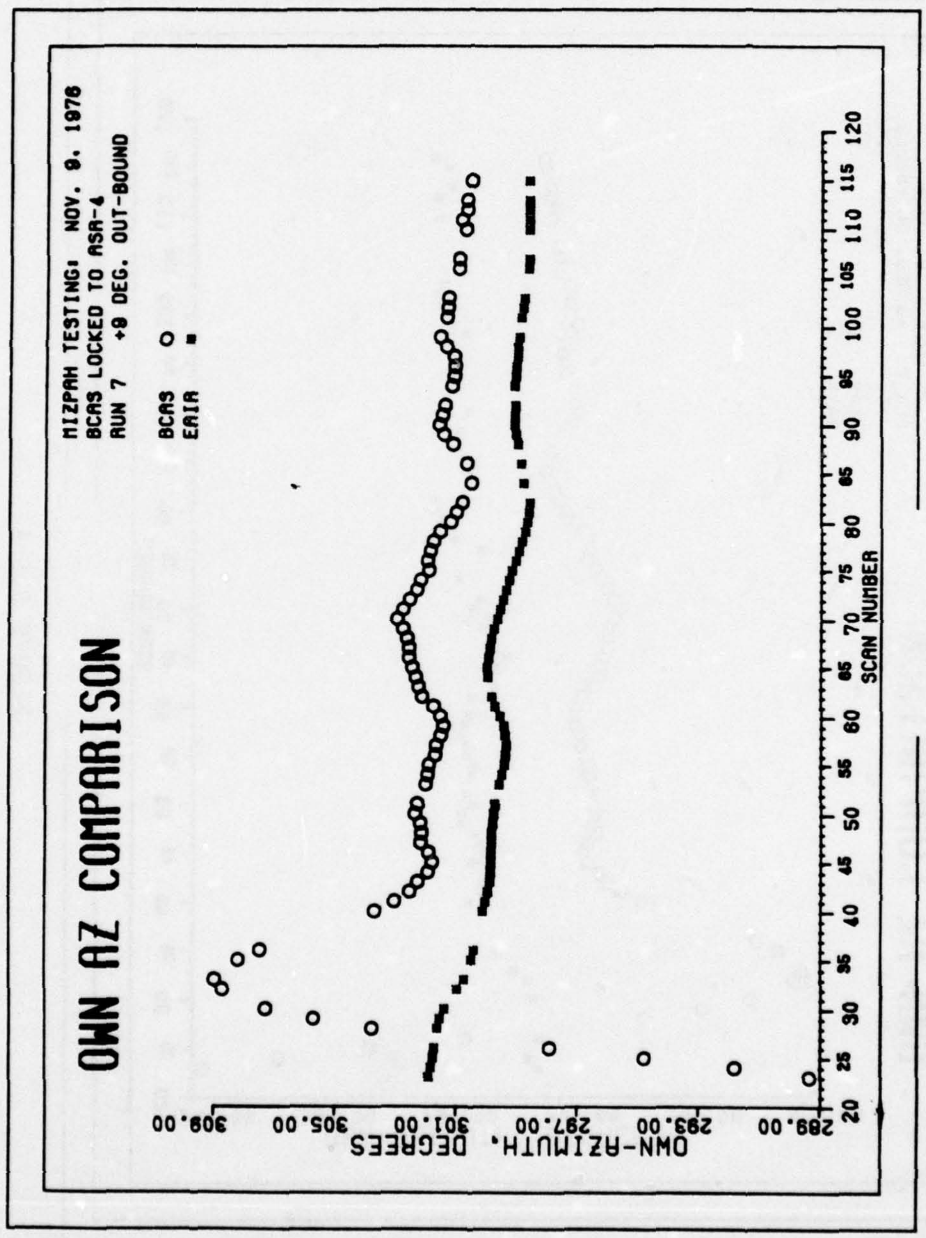

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 7 +9 DEG. OUT-BOUND
BCAS
EAIA
OWN-AZIMUTH, DEGREES
289.00
293.00
297.00
301.00
305.00
309.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.5-3

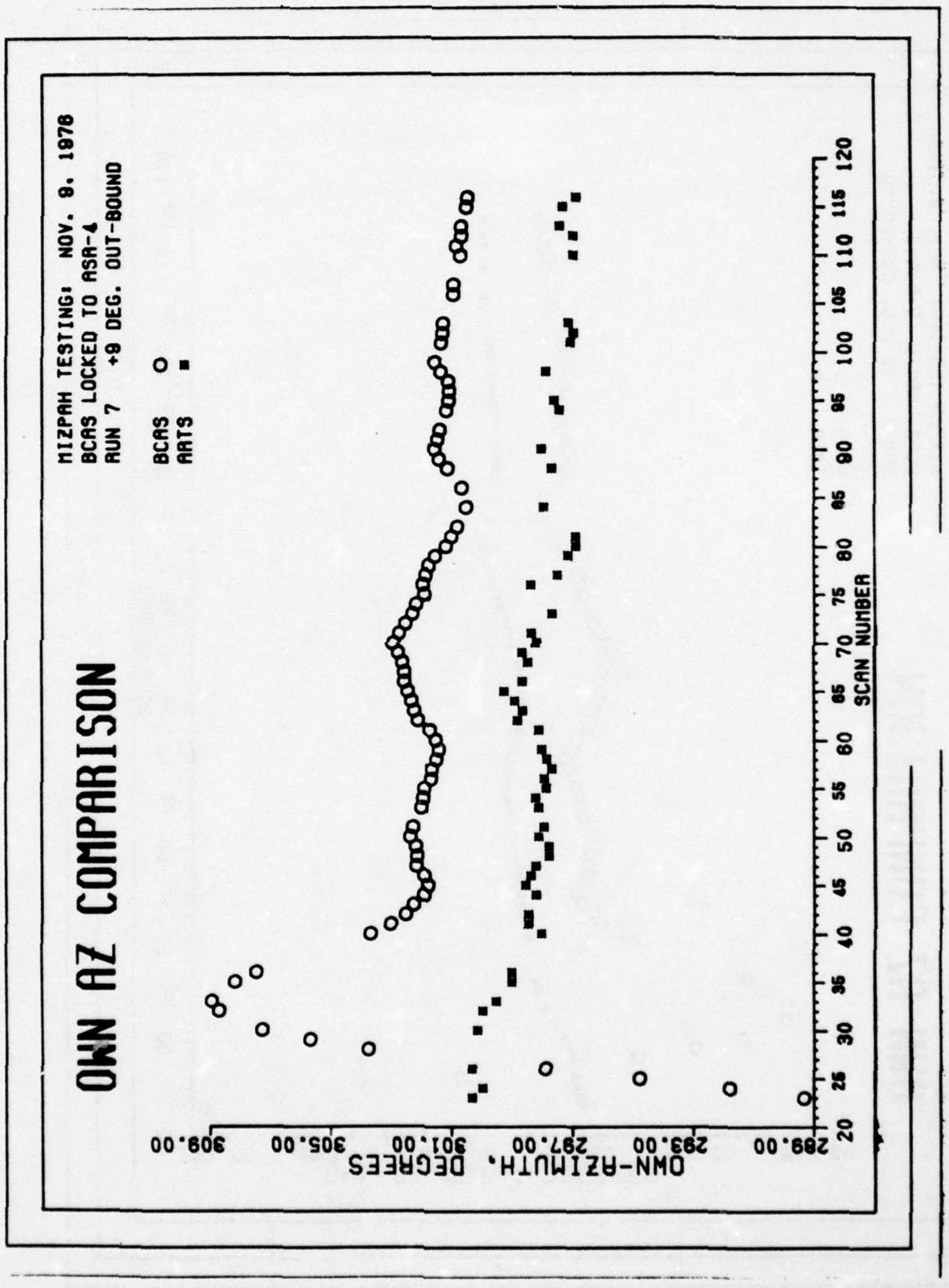

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9. 1978
BCAS LOCKED TO ASR-4
RUN 7 +9 DEG. OUT-BOUND
BCAS
ARTS
OWN-AZIMUTH, DEGREES
309.00
305.00
301.00
297.00
293.00
289.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.5-4

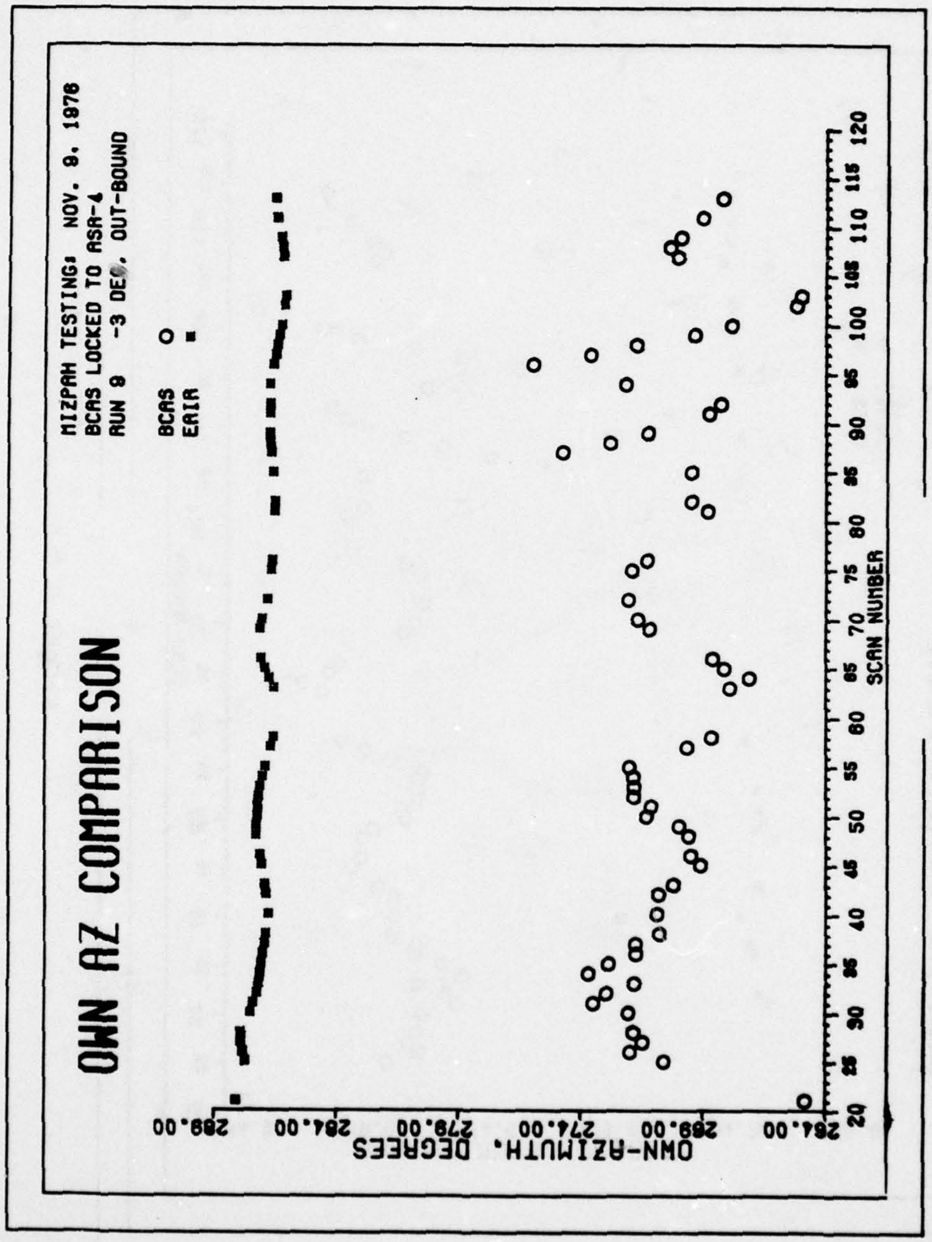

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9, 1978
BCAS LOCKED TO ASR-4
RUN 9 -3 DEG. OUT-BOUND
BCAS
EAIR
OWN-AZIMUTH, DEGREES
SCAN NUMBER
264.00
269.00
274.00
279.00
284.00
289.00
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120

FIGURE 5.5-5

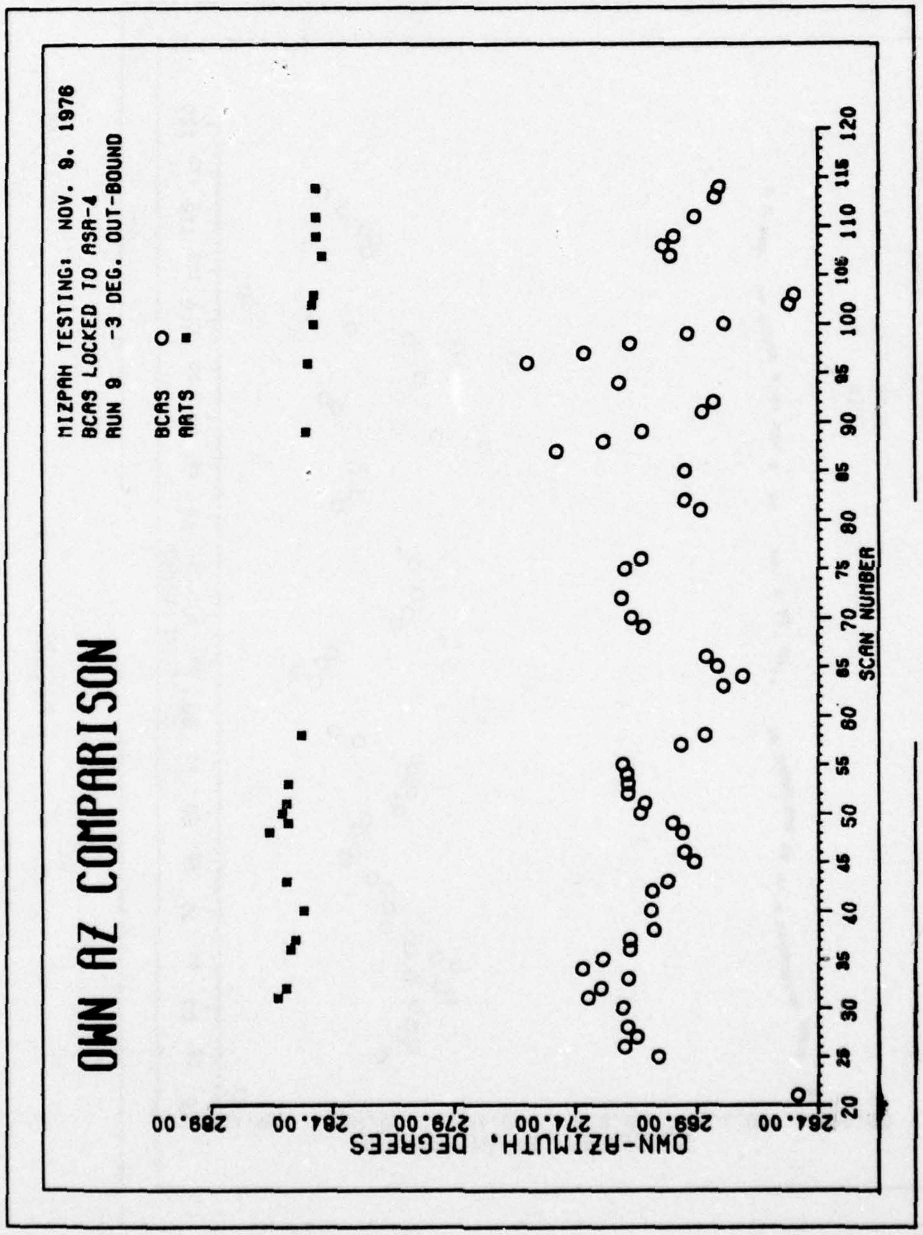
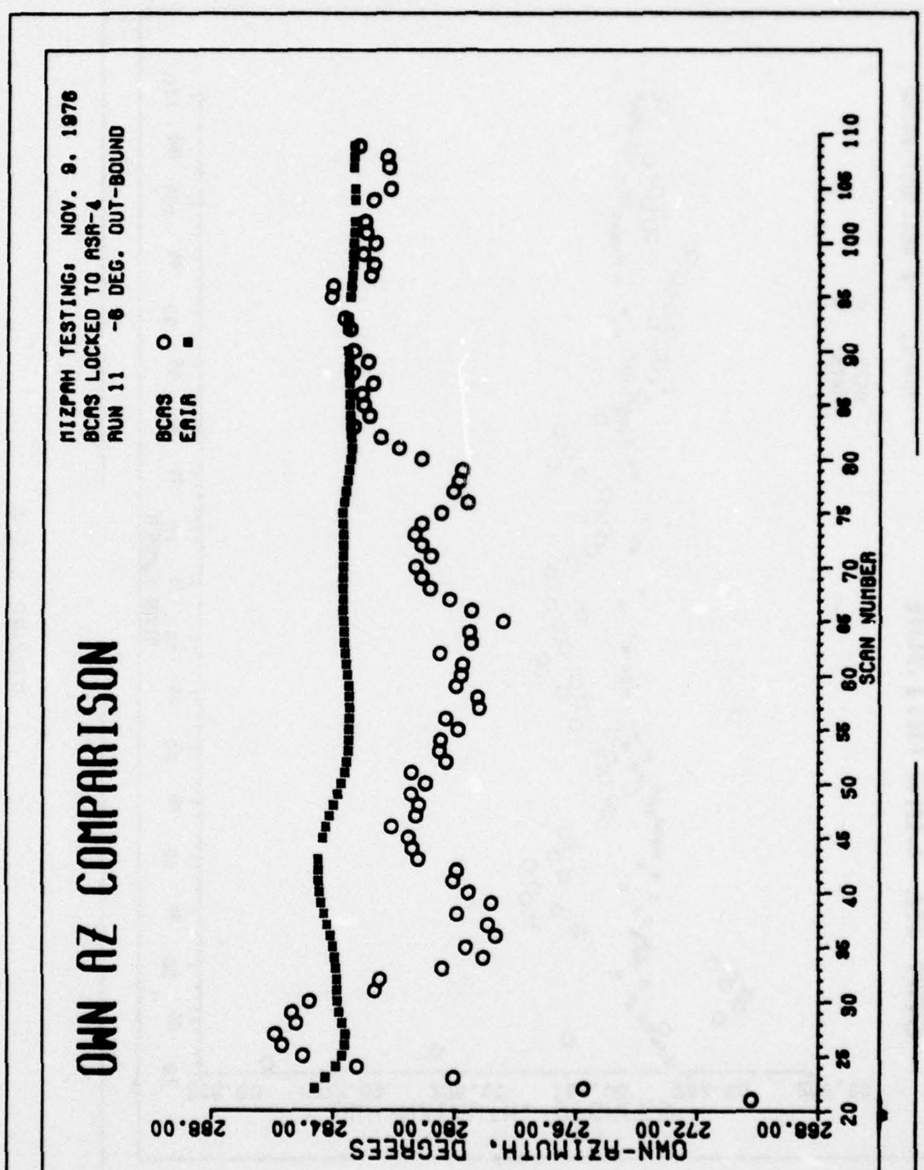

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9. 1976
BCAS LOCKED TO ASR-4
RUN 9 -3 DEG. OUT-BOUND
BCAS
AATS
SCAN NUMBER
OWN-AZIMUTH, DEGREES

FIGURE 5.5-6



OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9, 1976
BCAS LOCKED TO ASR-4
RUN 11 -8 DEG. OUT-BOUND
BCAS
EAIA
OWN-AZIMUTH, DEGREES
288.00
284.00
280.00
276.00
272.00
268.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110

FIGURE 5.5-7

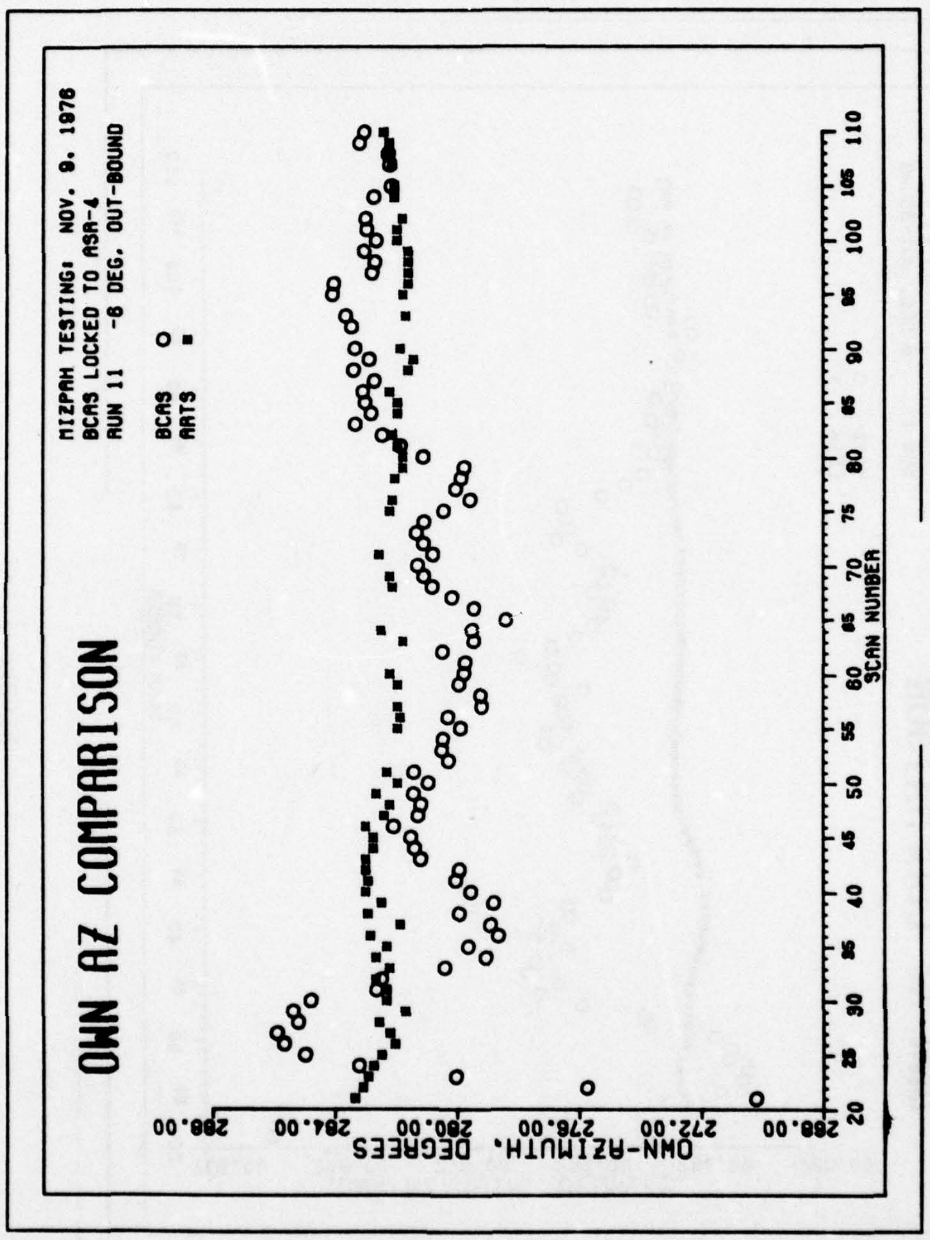

OWN AZ COMPARISON
MIZPAH TESTING: NOV. 9, 1976
BCAS LOCKED TO ASR-4
RUN 11 -6 DEG. OUT-BOUND
BCAS
ARTS
OWN-AZIMUTH, DEGREES
268.00
272.00
276.00
280.00
284.00
288.00
SCAN NUMBER
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110

FIGURE 5.5-8

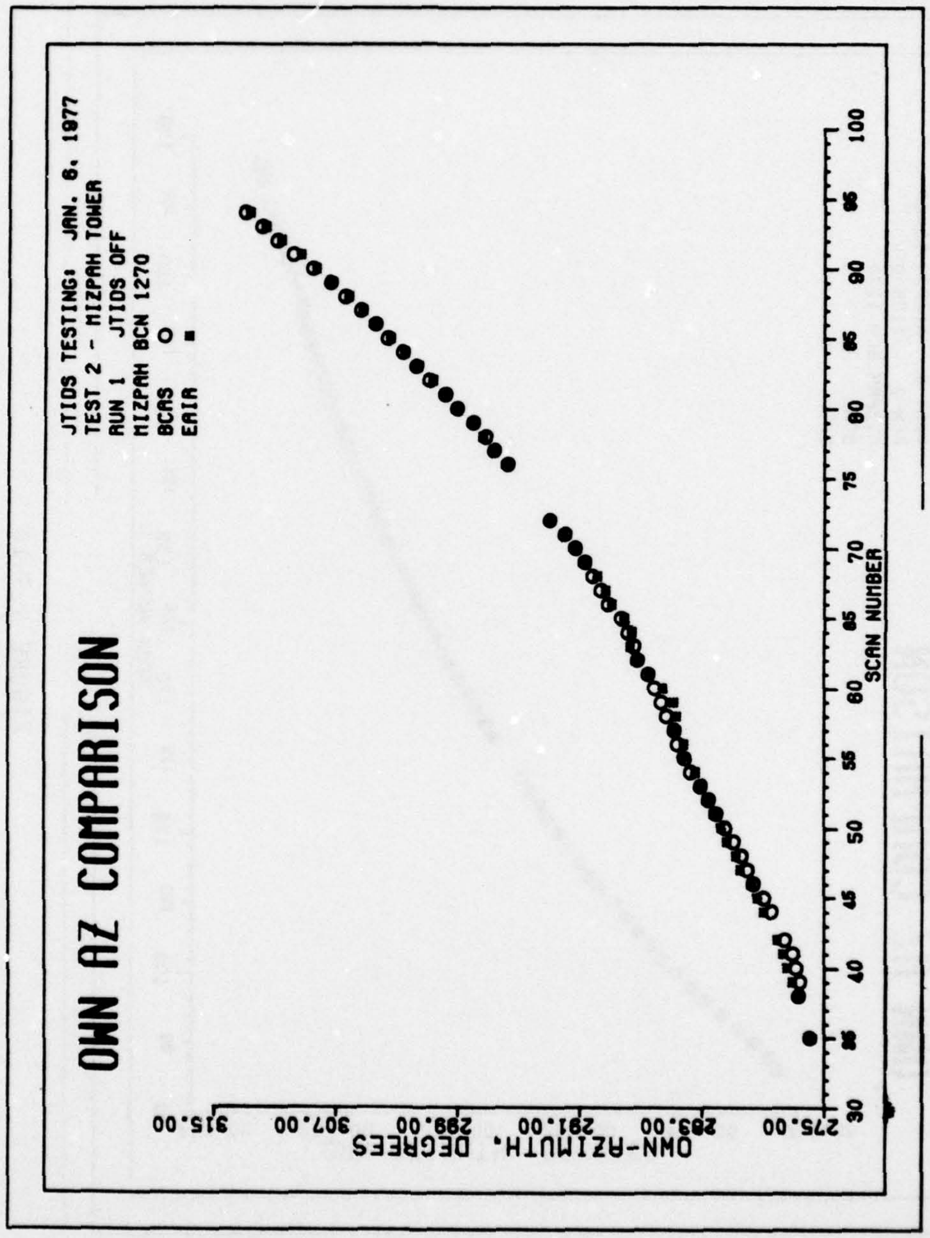

OWN AZ COMPARISON
JTIDS TESTING: JAN. 6, 1977
TEST 2 - MIZPAH TOWER
RUN 1 JTIDS OFF
MIZPAH BCN 1270
BCAS
EAIR
OWN-AZIMUTH, DEGREES
275.00
283.00
291.00
299.00
307.00
315.00
SCAN NUMBER
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

FIGURE 5.5-9

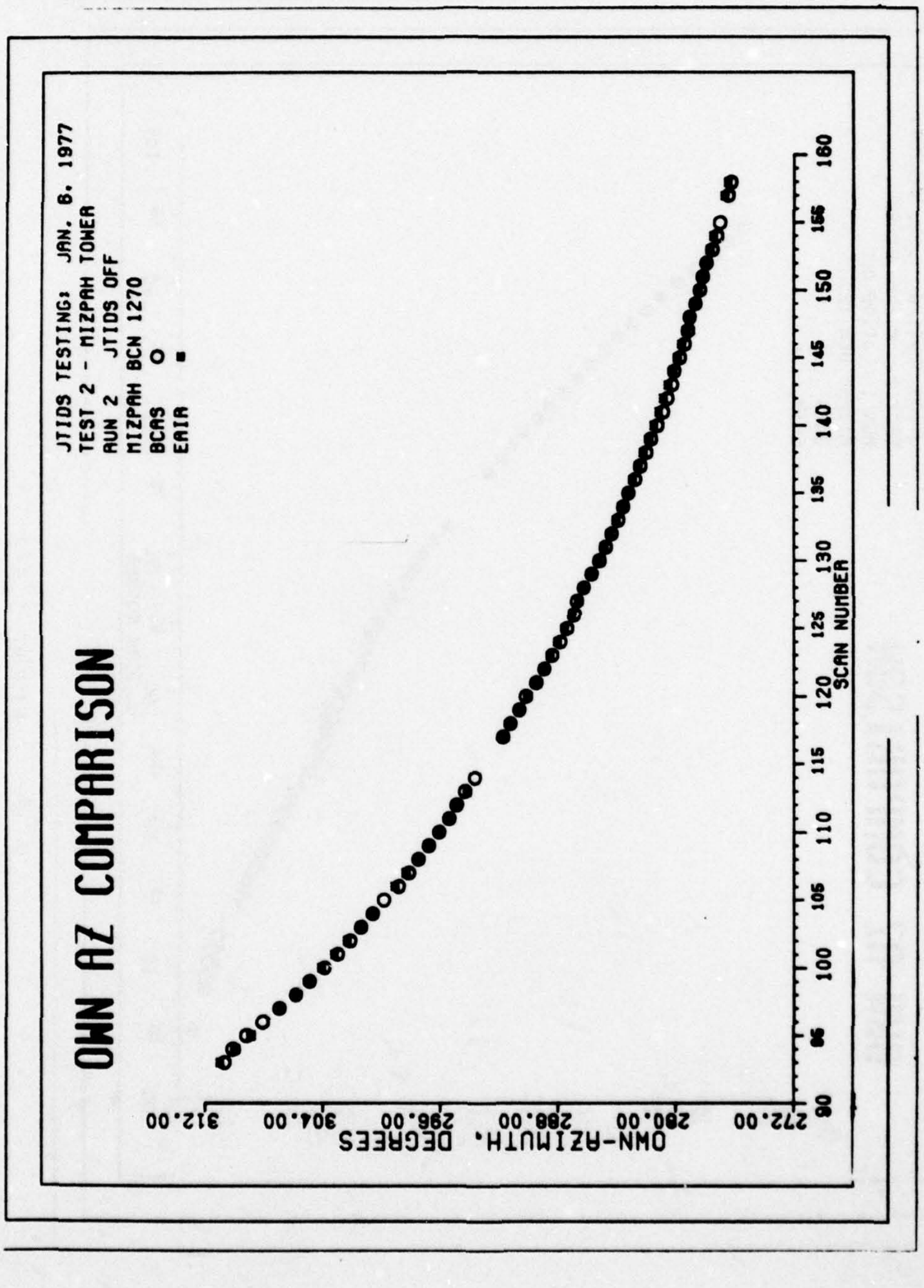

OWN AZ COMPARISON
JTIDS TESTING; JAN. 6. 1977
TEST 2 - MIZPAH TOWER
RUN 2 JTIDS OFF
MIZPAH BCN 1270
BCAS O
EAIR ■
OWN-AZIMUTH, DEGREES
312.00
304.00
296.00
288.00
280.00
272.00
SCAN NUMBER
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160

FIGURE 5.5-10

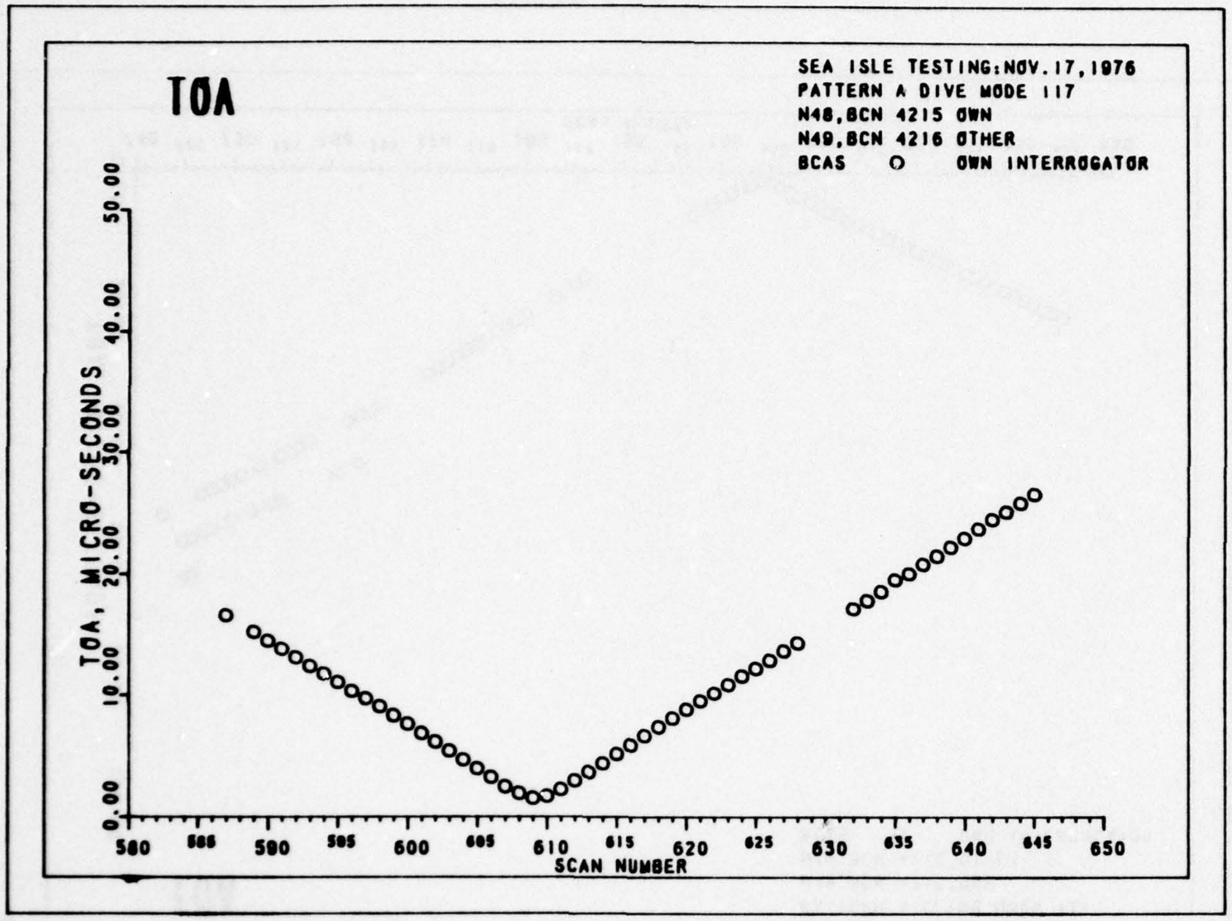


FIGURE 5.16-12

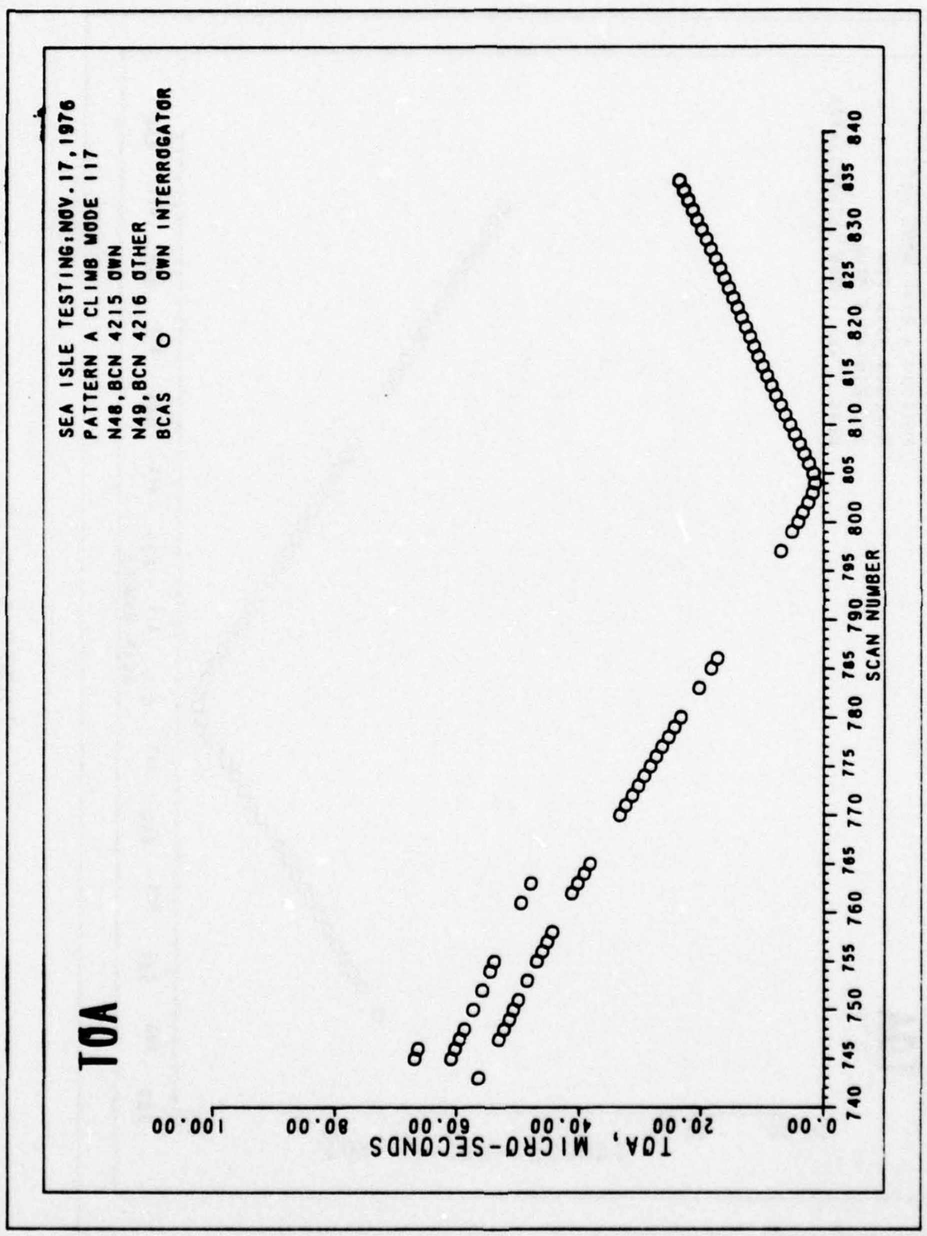


FIGURE 5.16-13

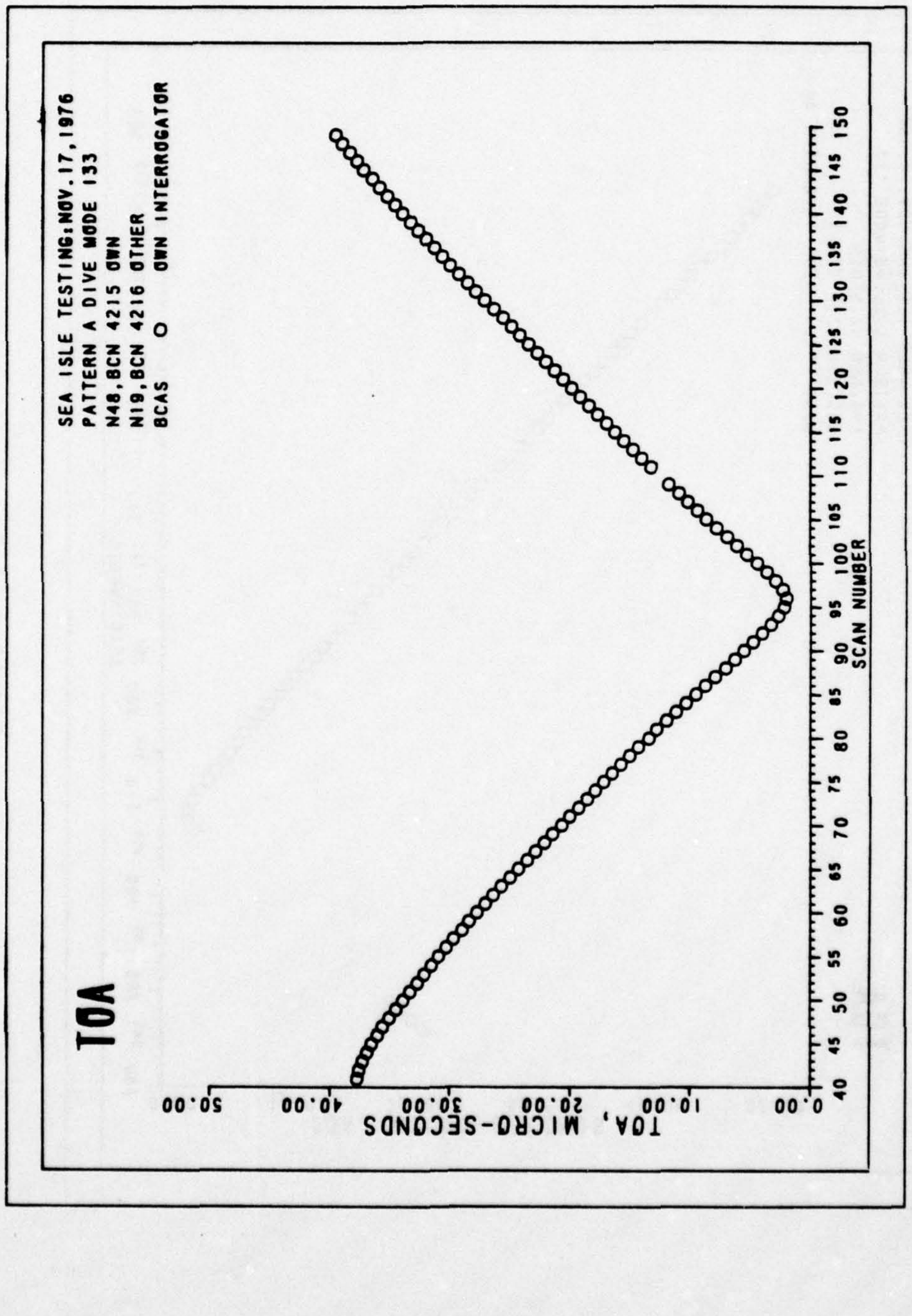


FIGURE 5.16-14

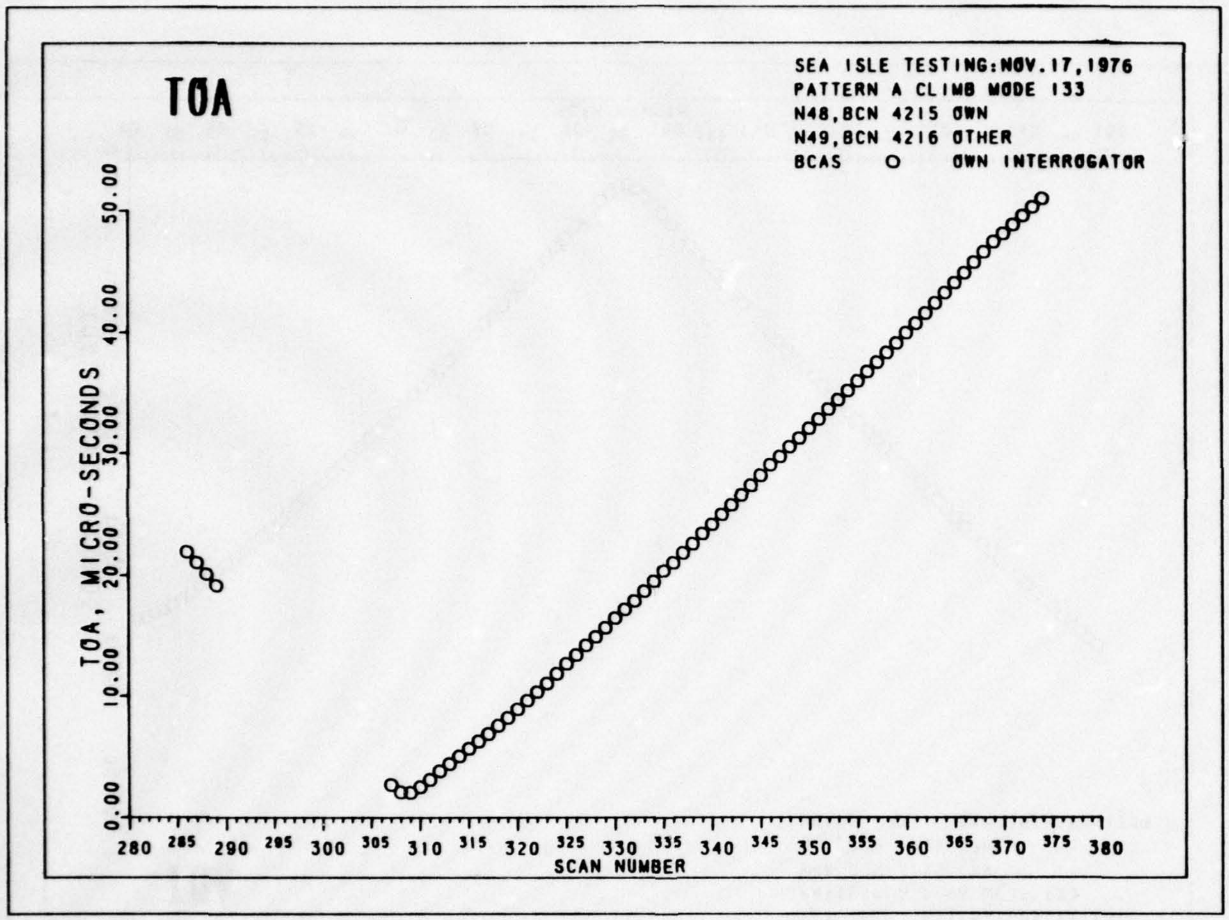


FIGURE 5.16-15

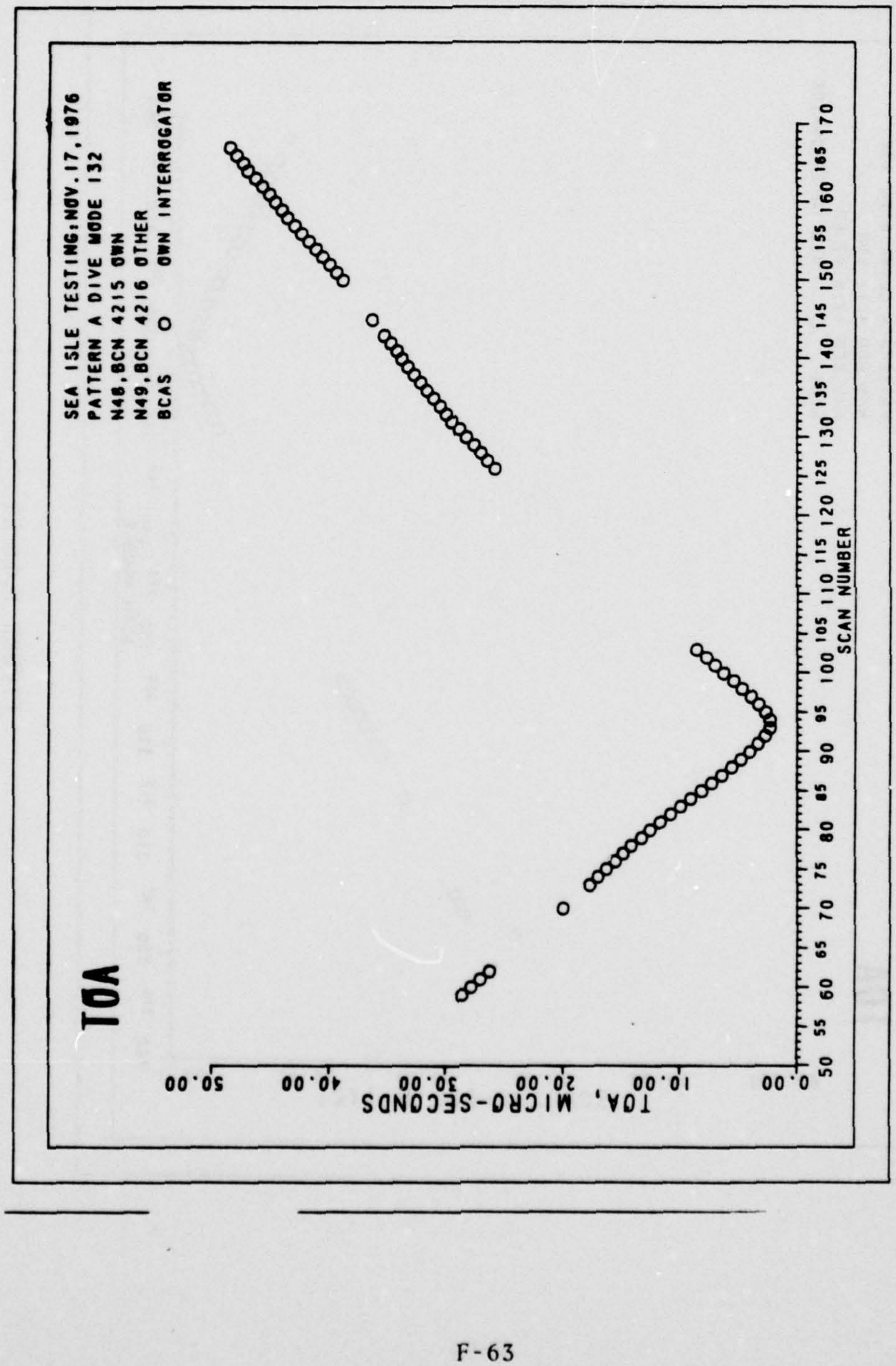


FIGURE 5.16-16

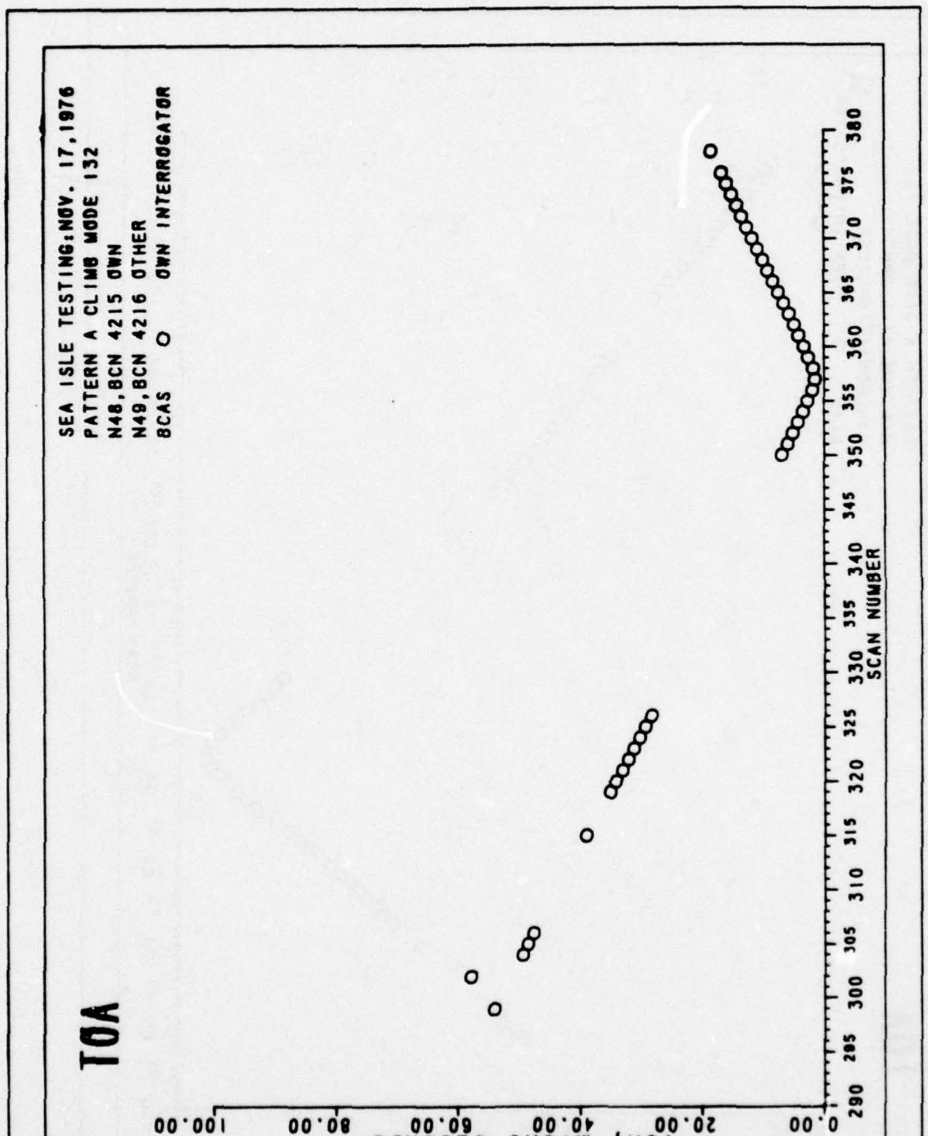


FIGURE 5.16-17

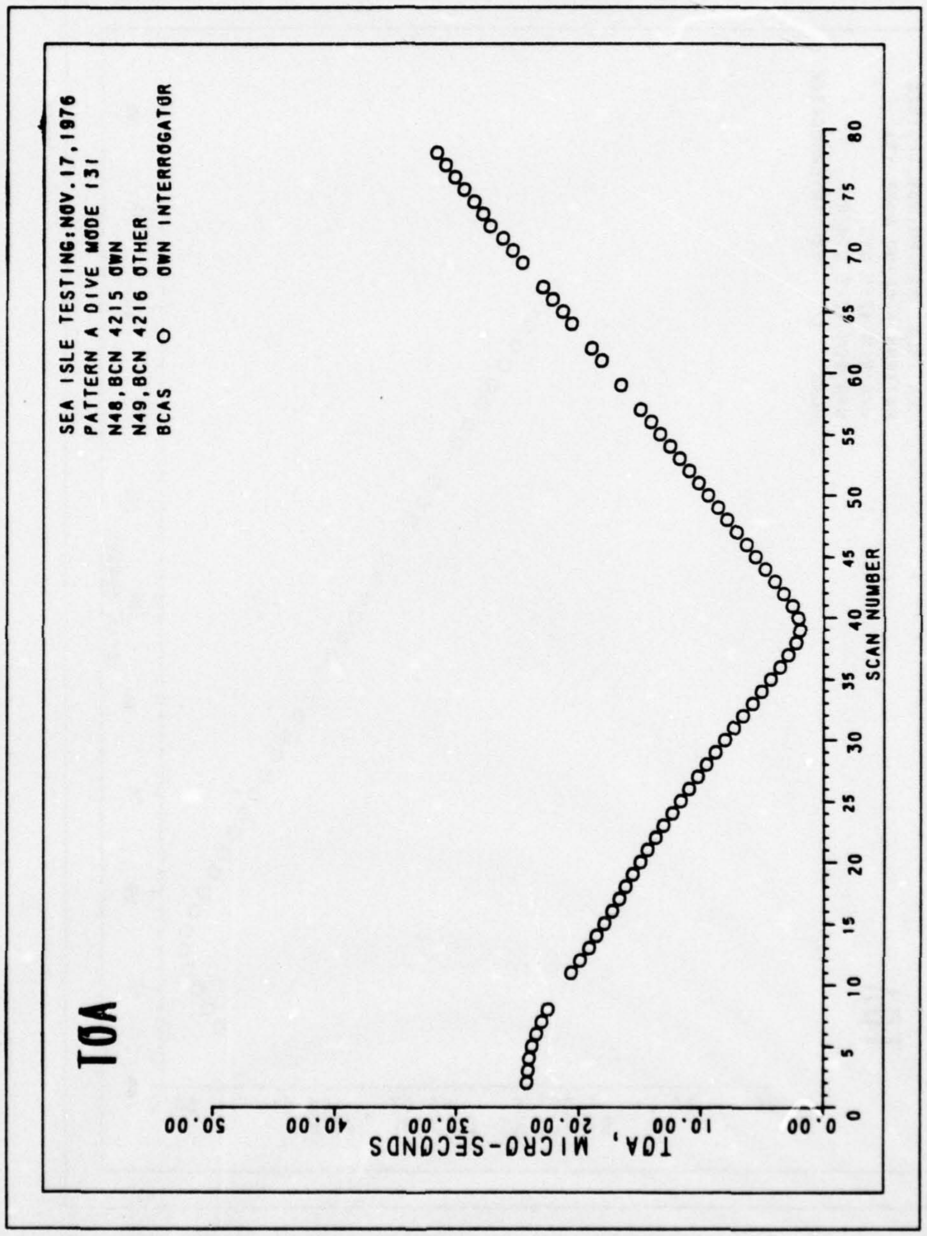


FIGURE 5.16-18

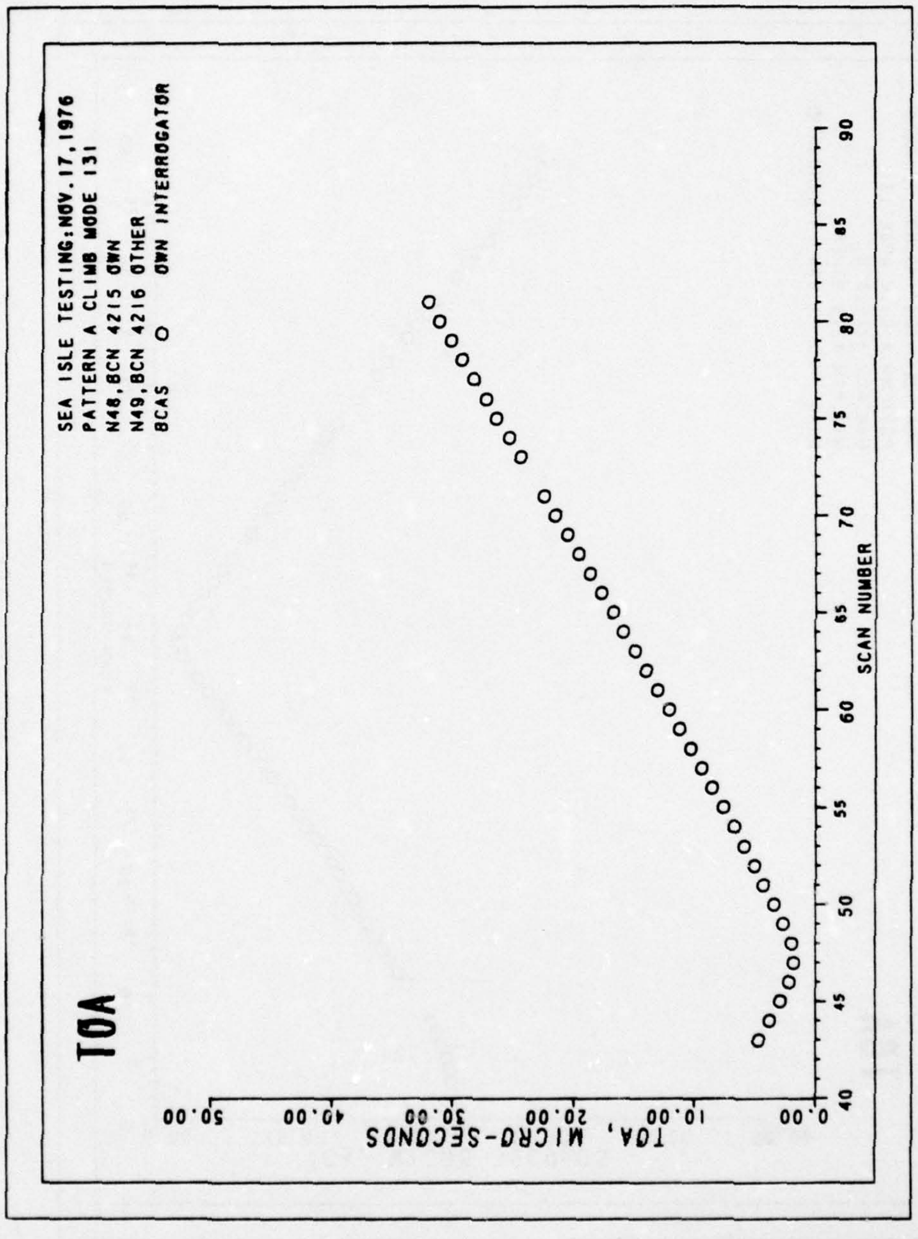


FIGURE 5.16-19

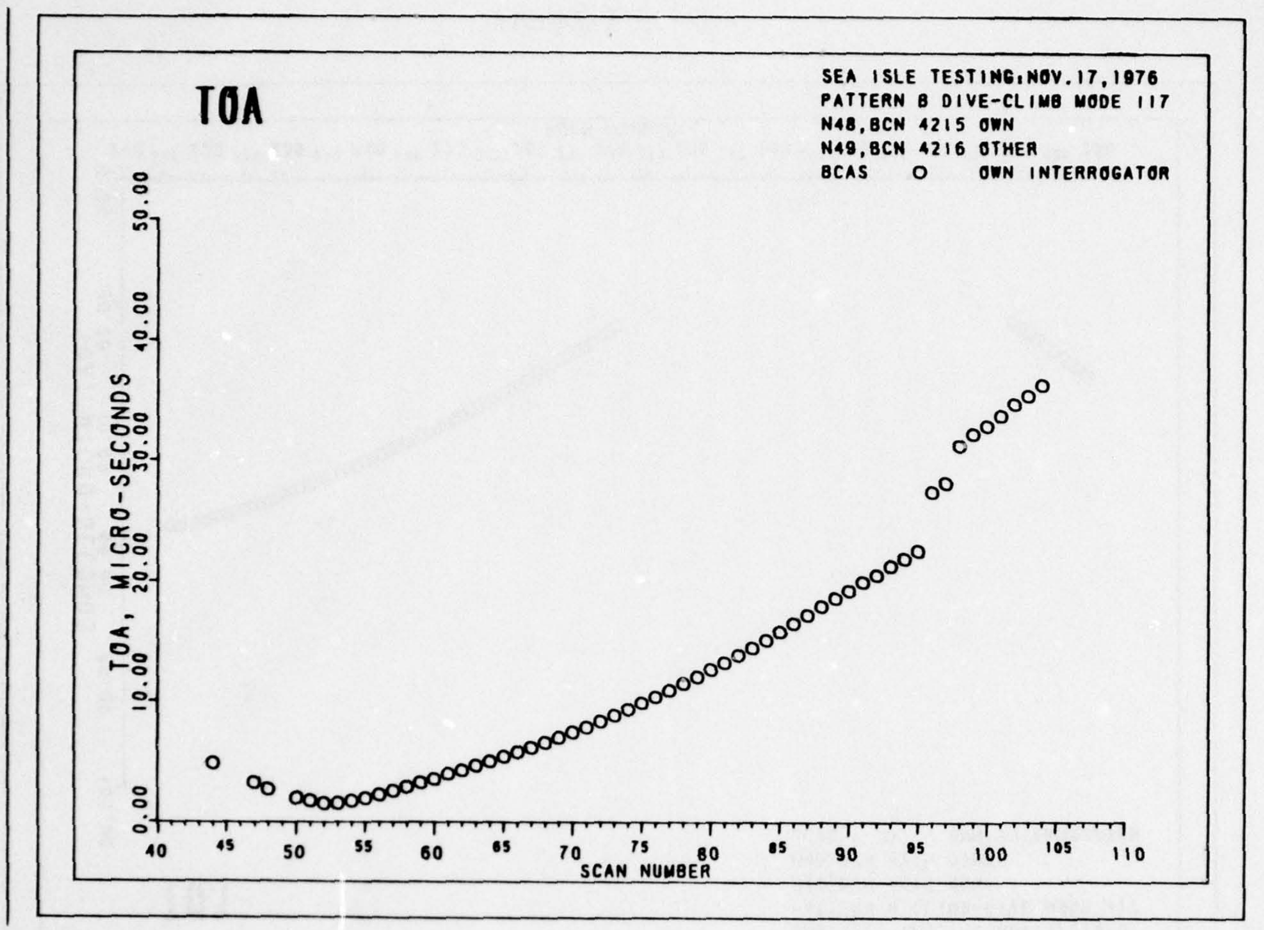


FIGURE 5.16-20

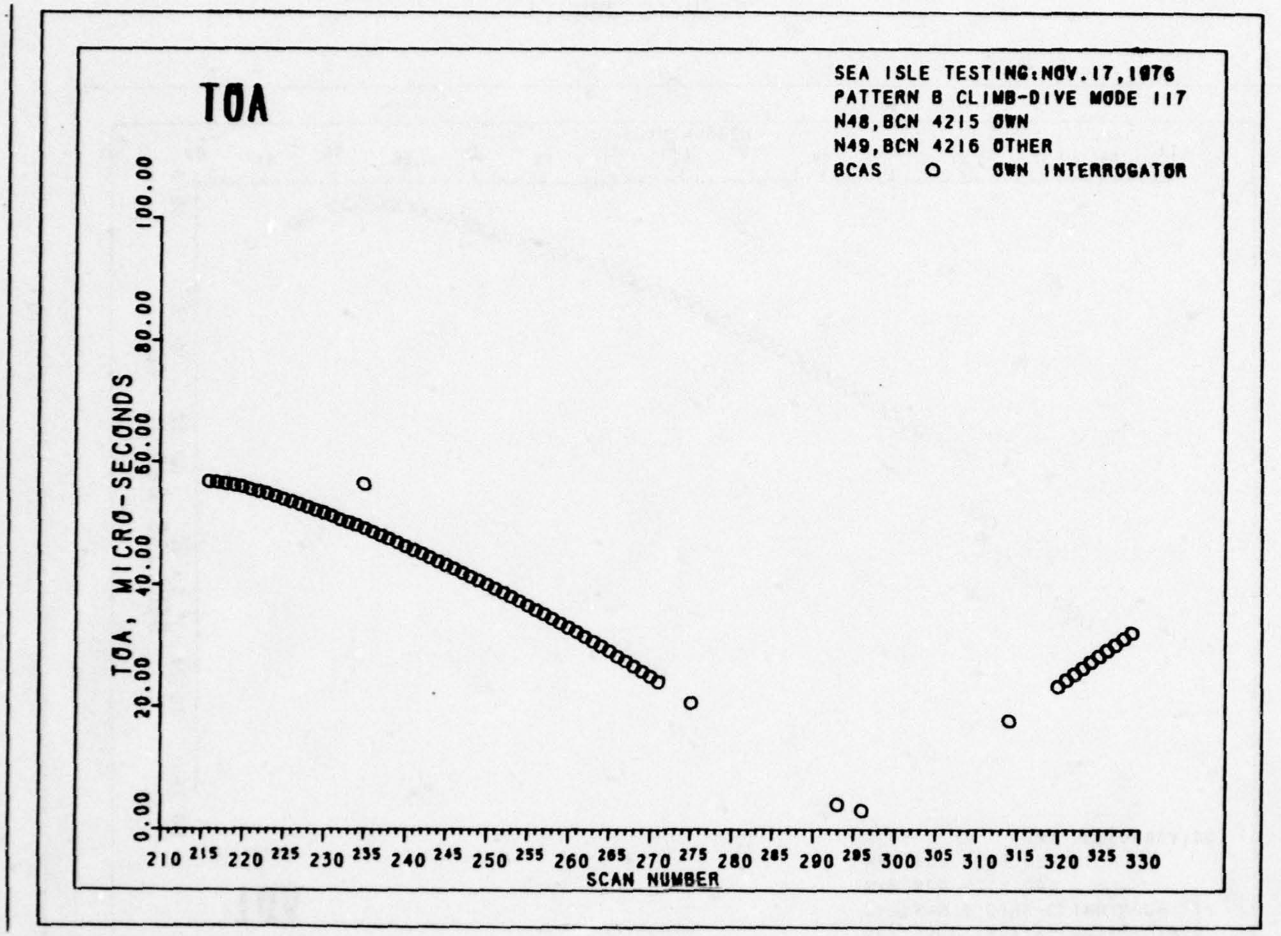


FIGURE 5.16-21

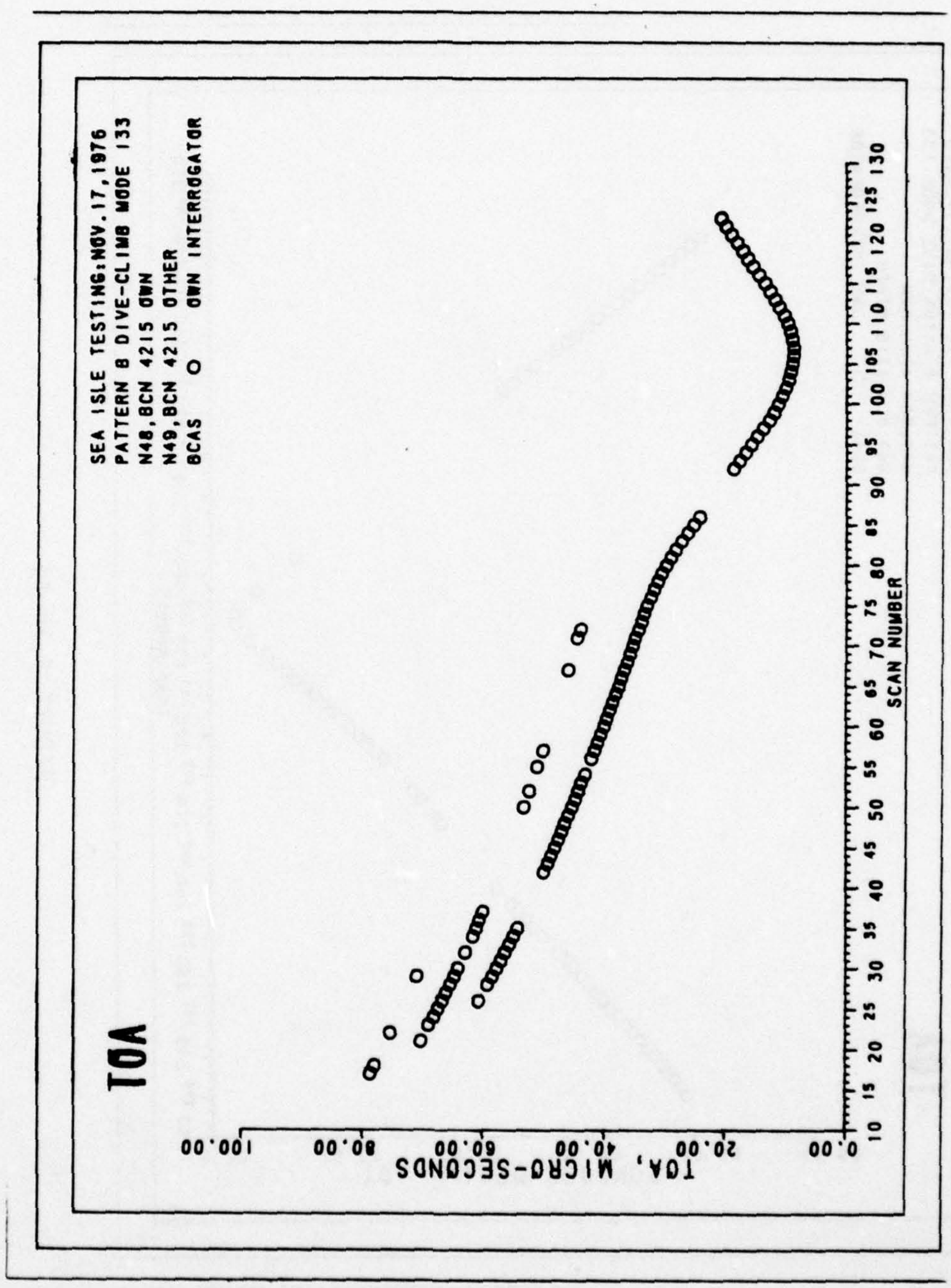


FIGURE 5.16-22

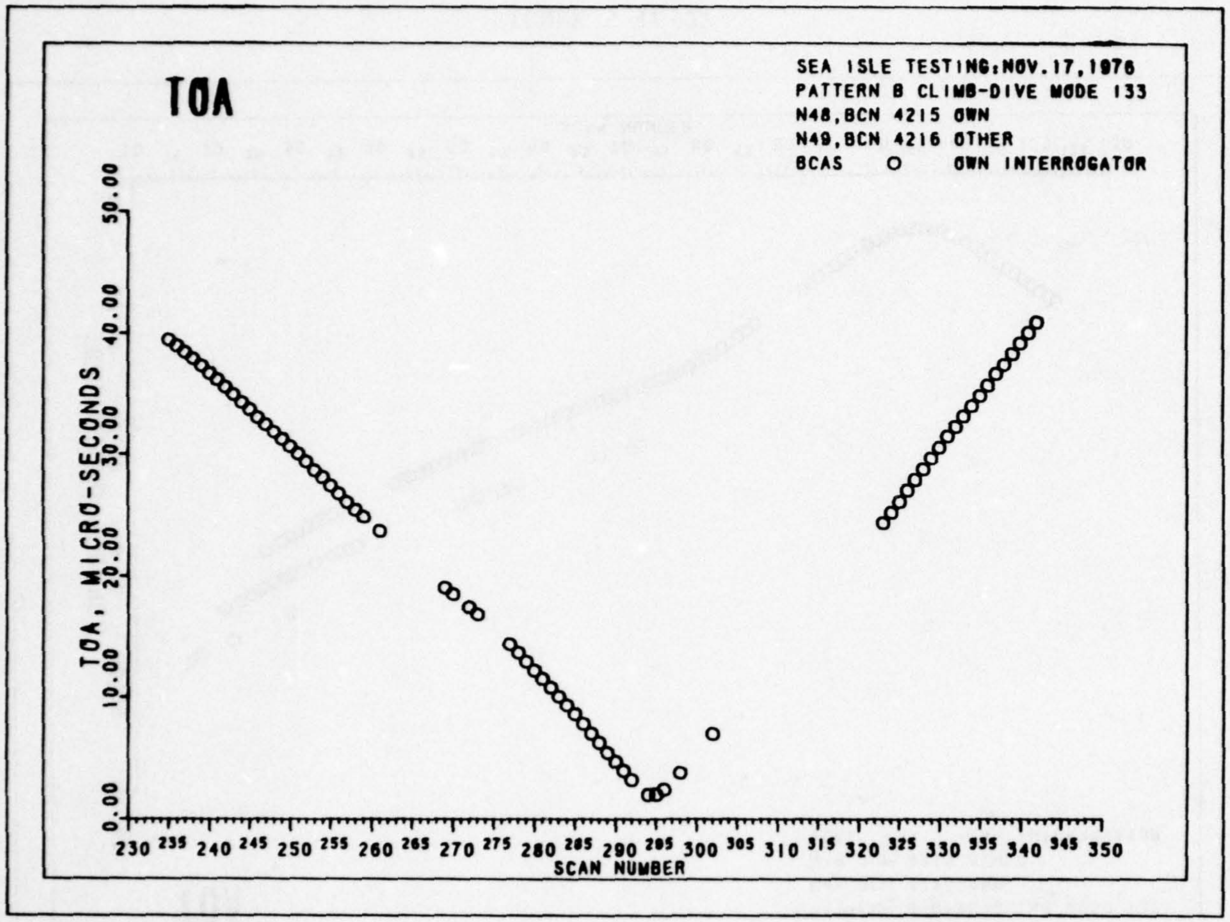


FIGURE 5.16-23

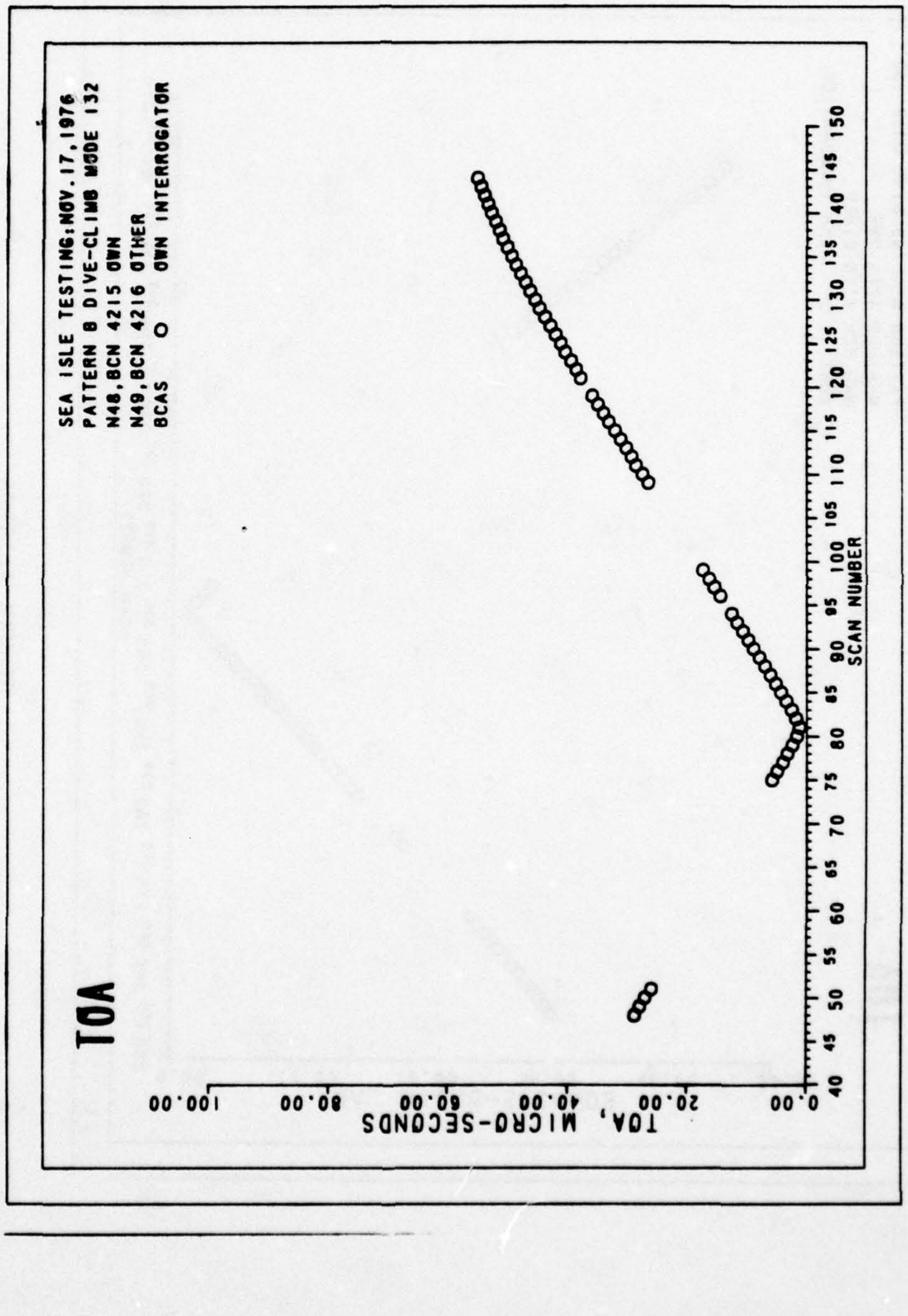


FIGURE 5.16-24

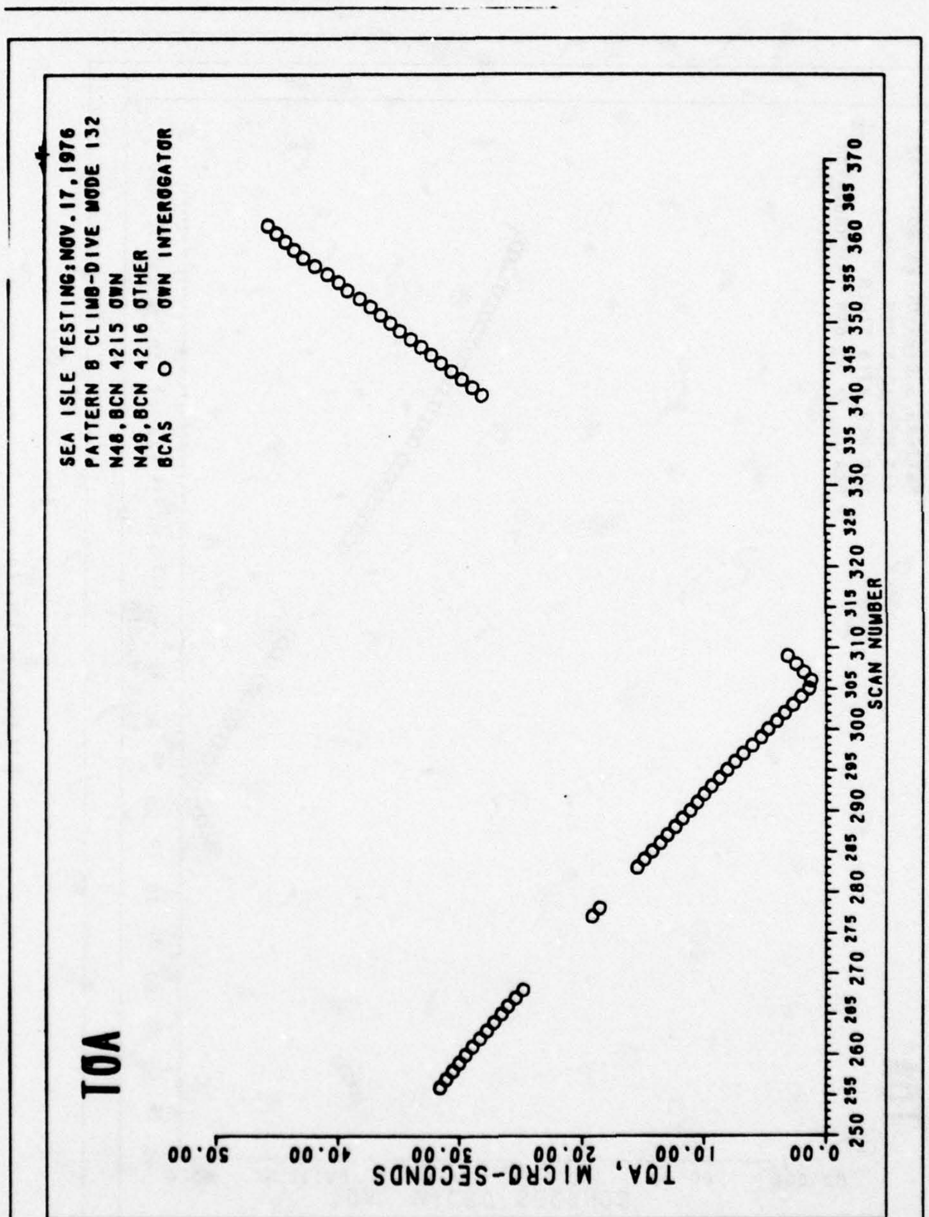


FIGURE 5.16-25

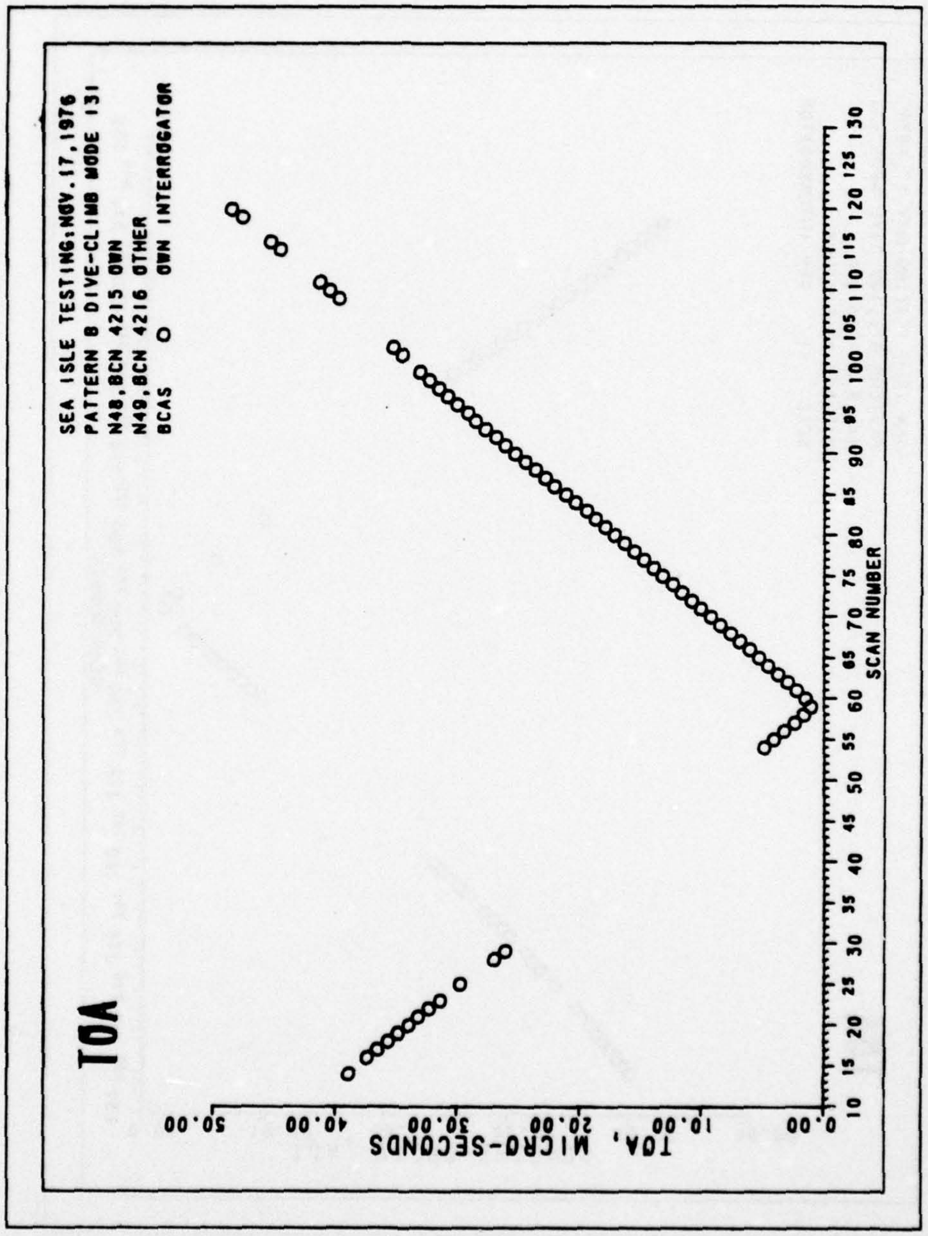


FIGURE 5.16-26

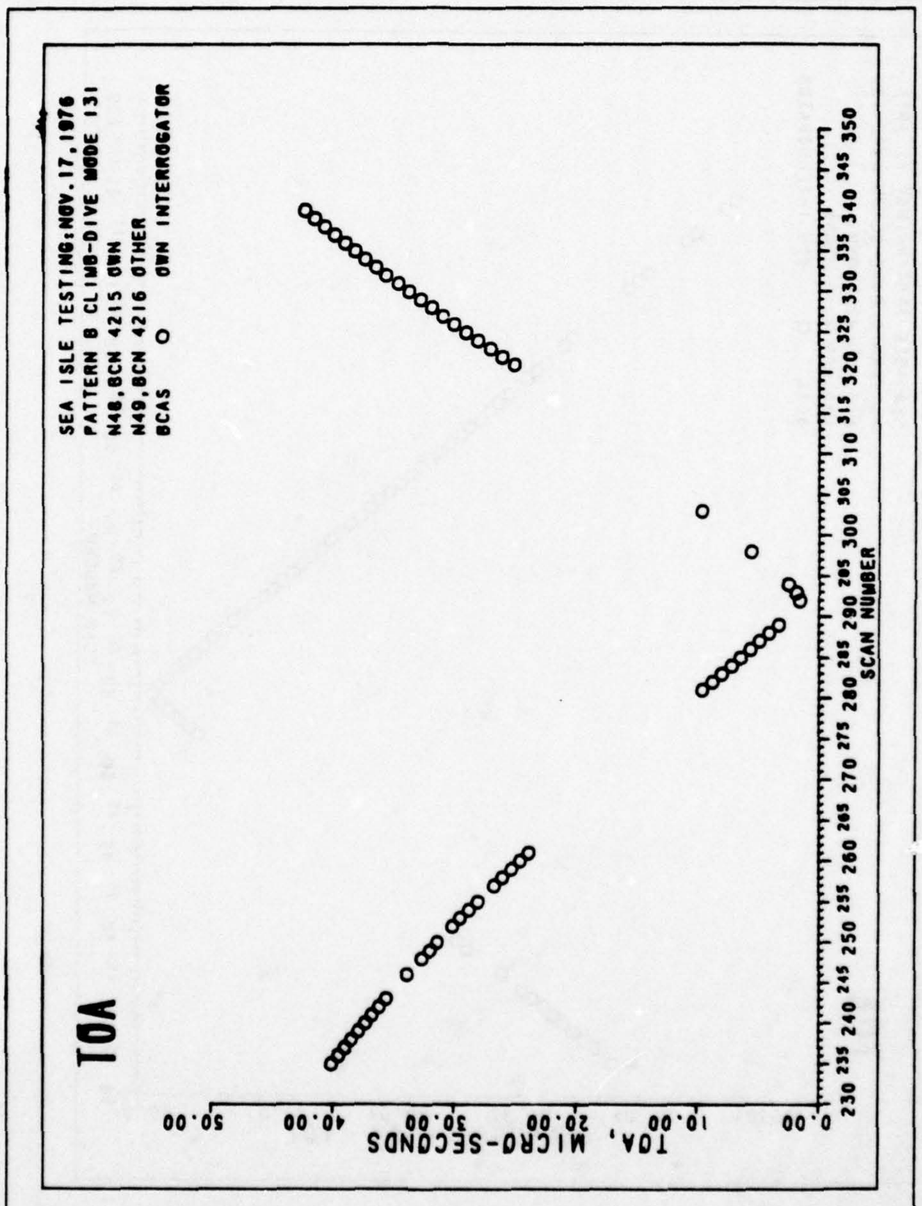


FIGURE 5.16-27

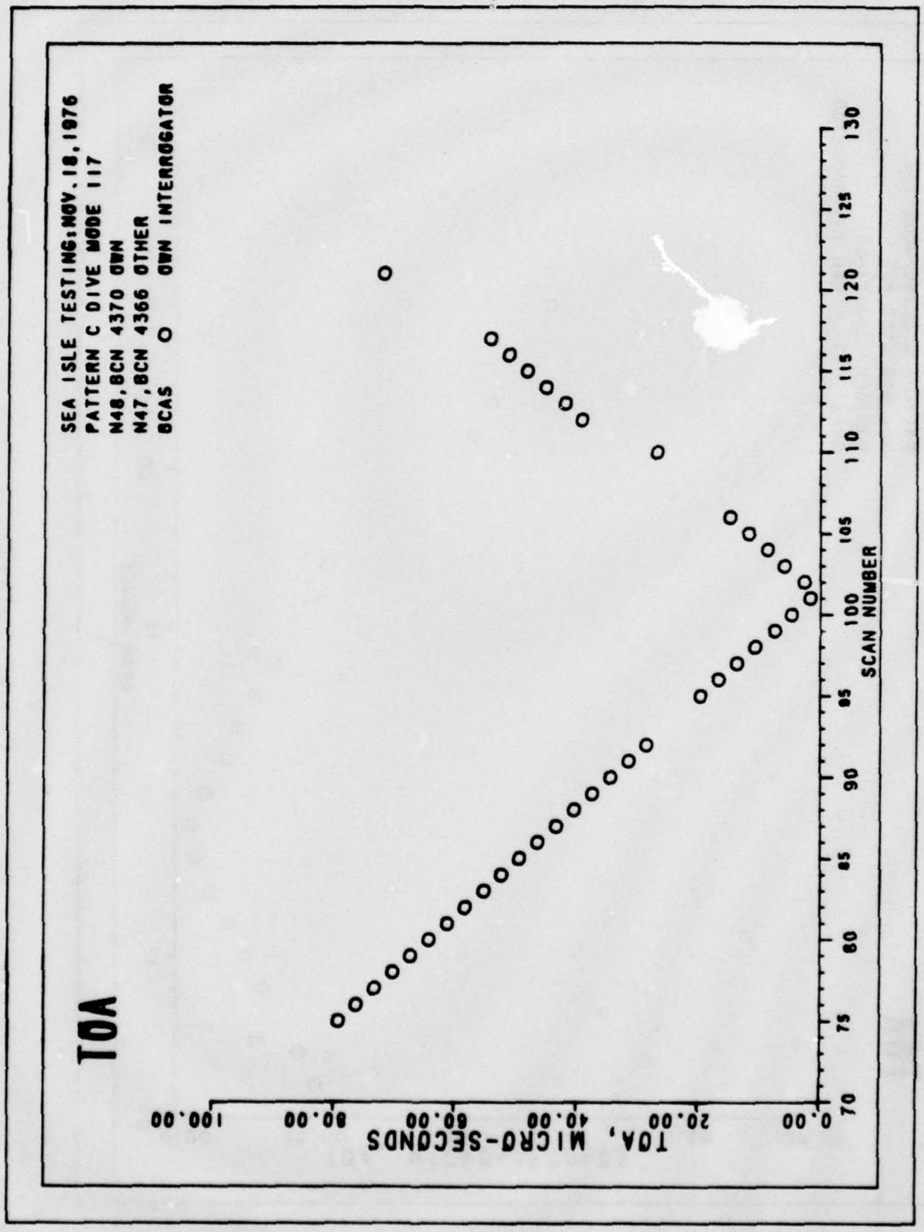


FIGURE 5.16-28

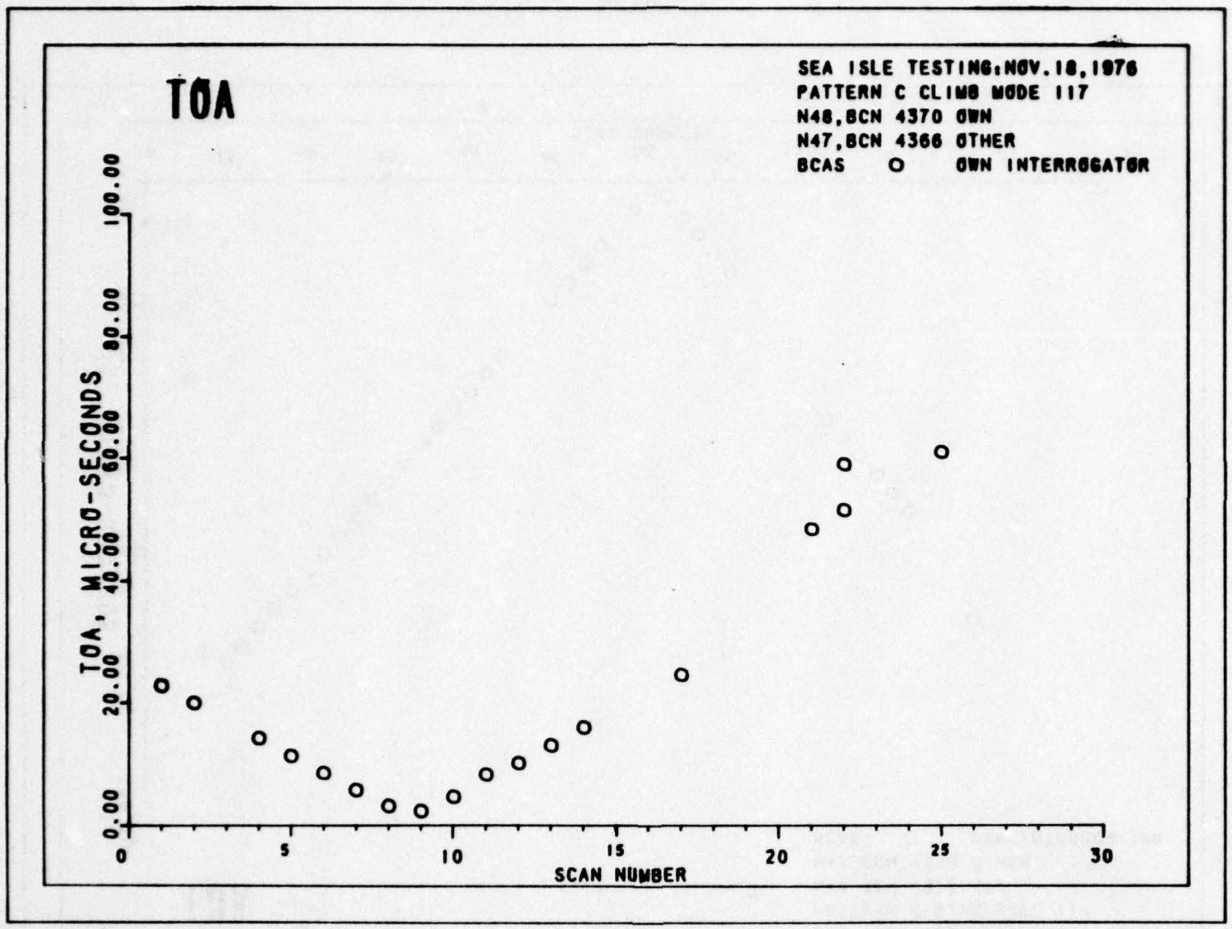


FIGURE 5.16-29

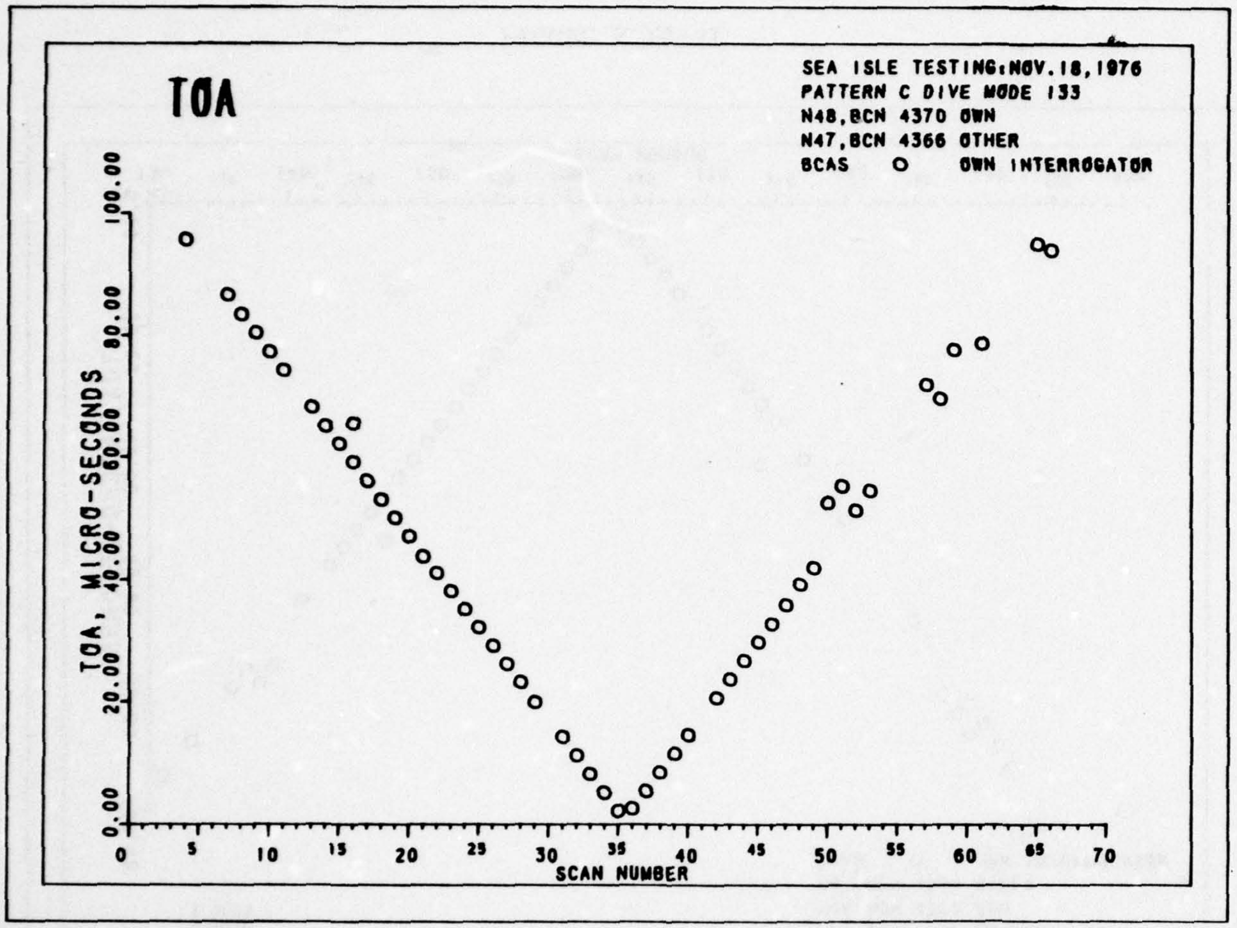


FIGURE 5.16-30

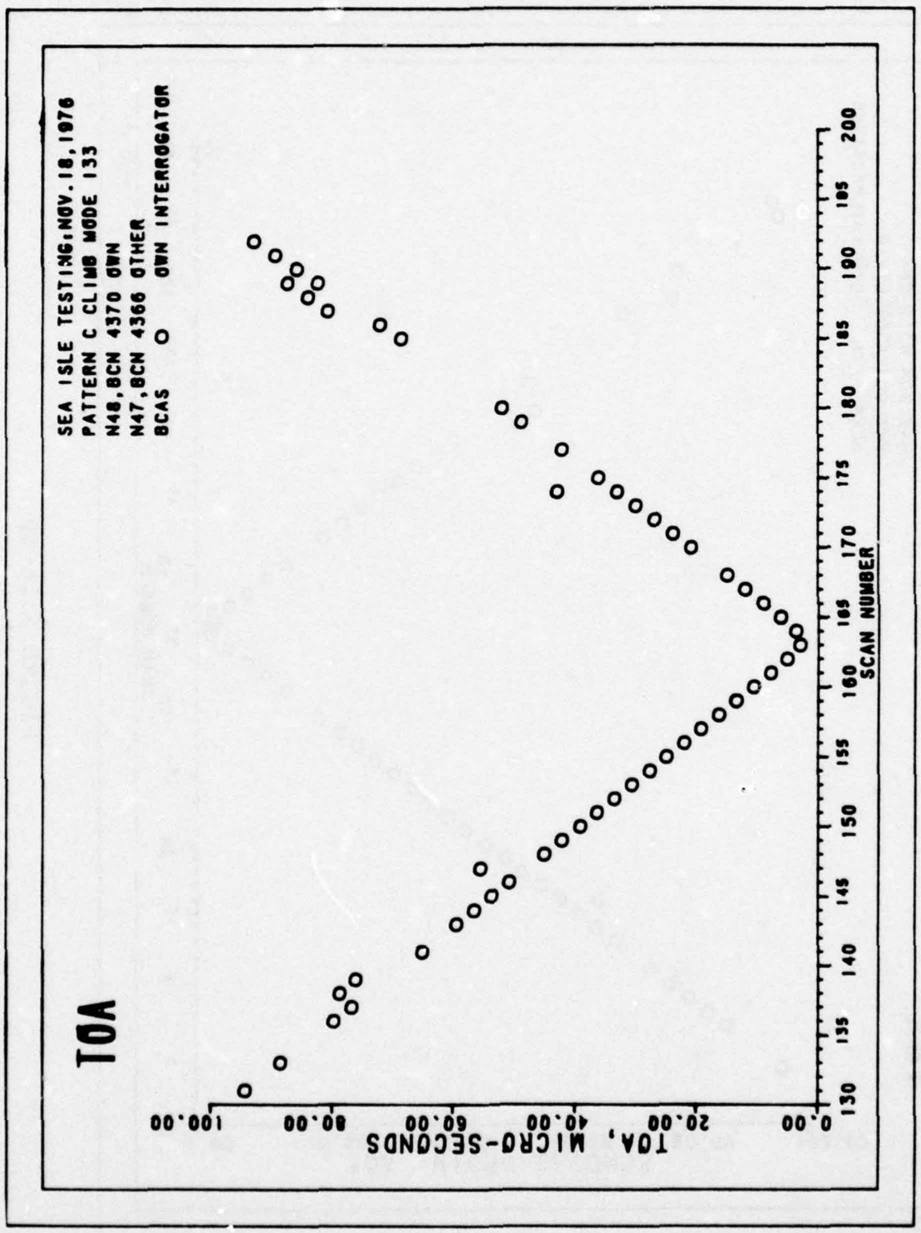


FIGURE 5.16-31

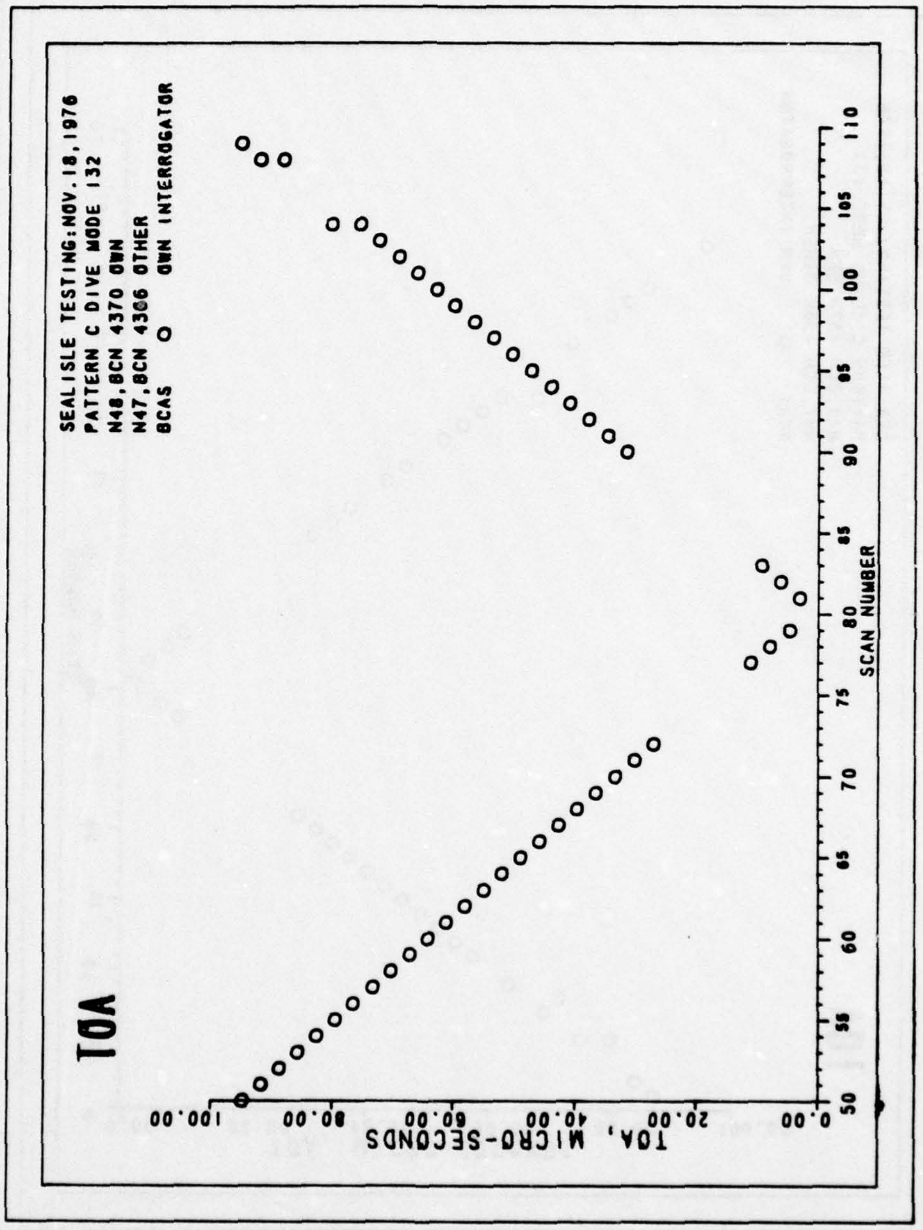


FIGURE 5.16-32

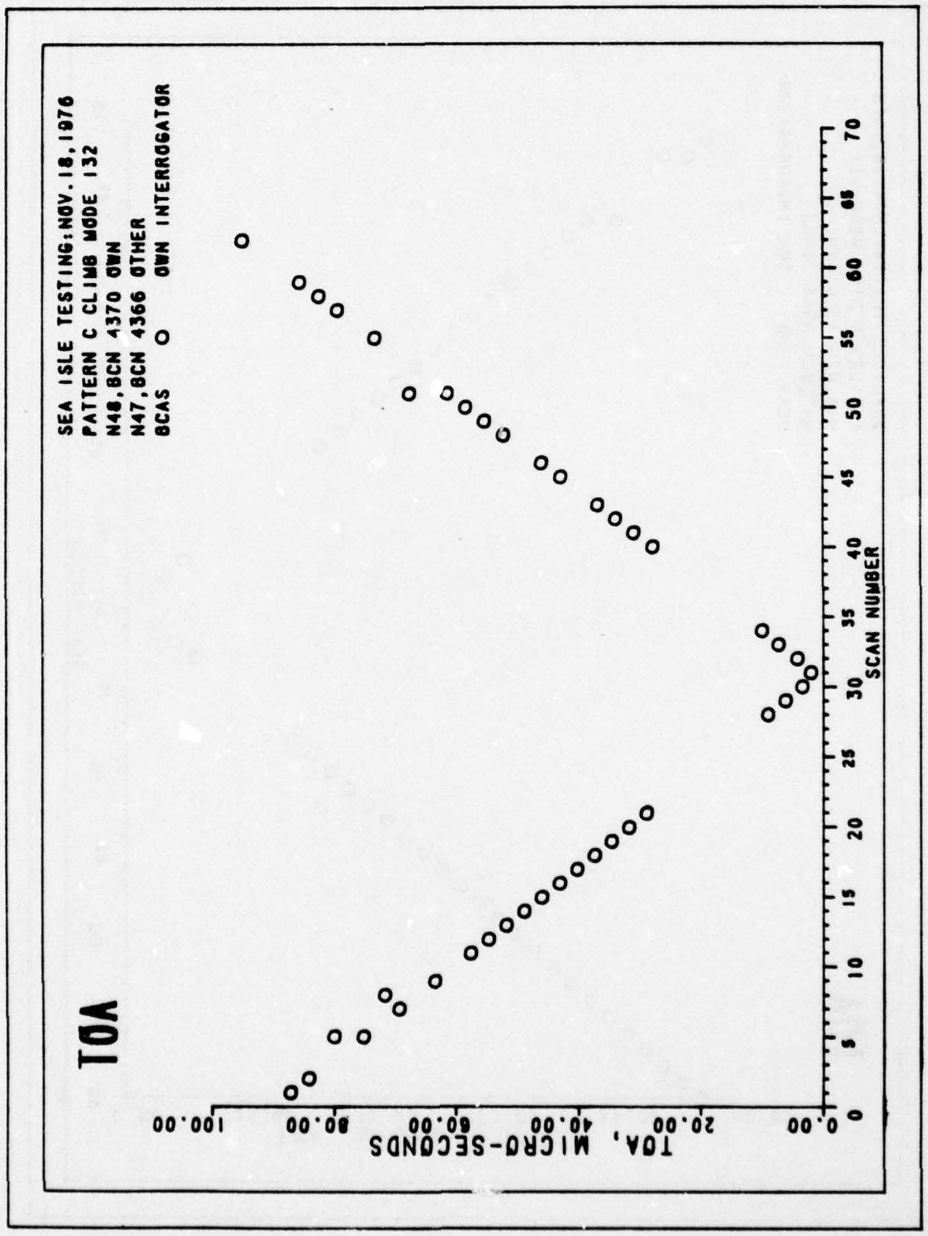


FIGURE 5.16-33

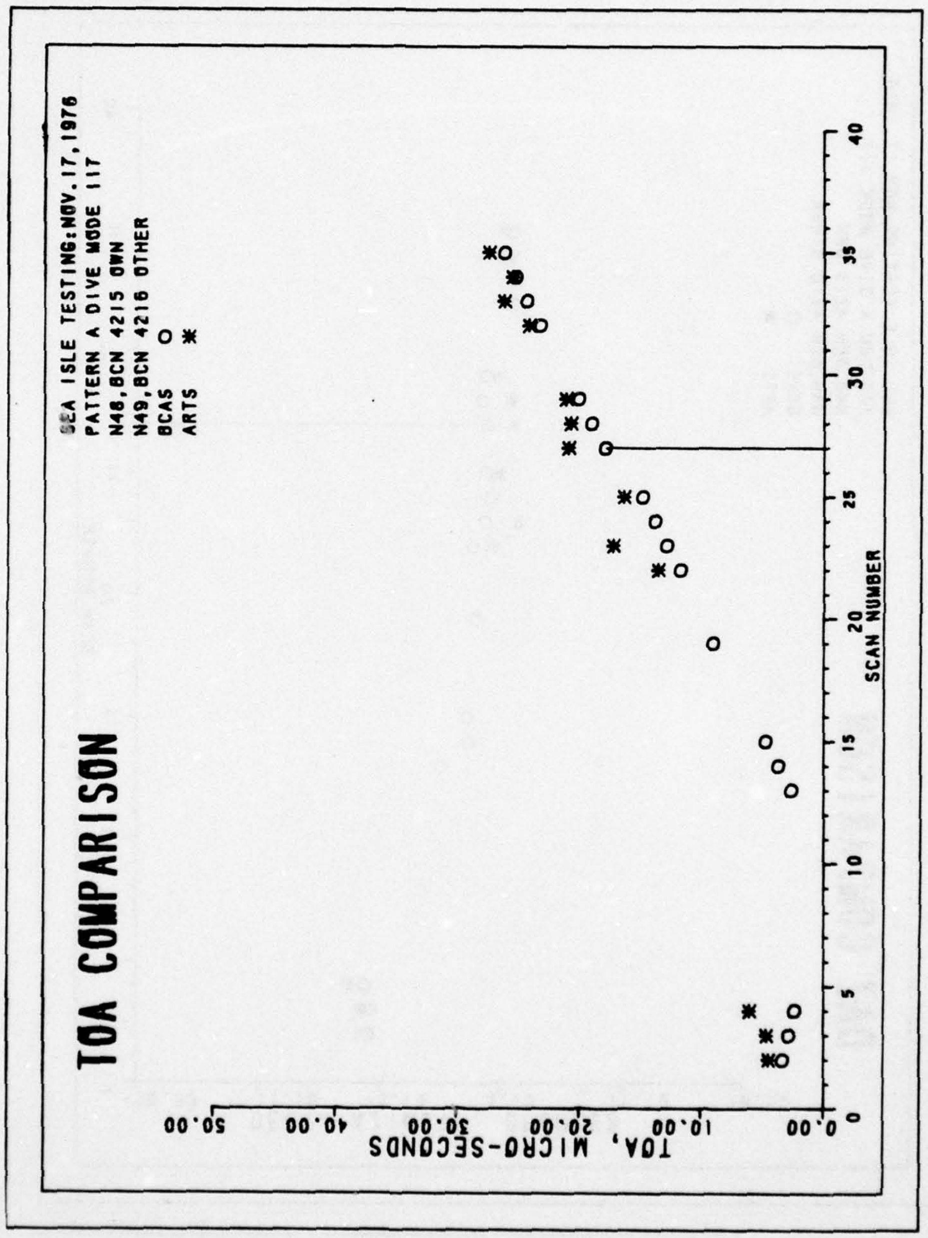


FIGURE 5.16-34

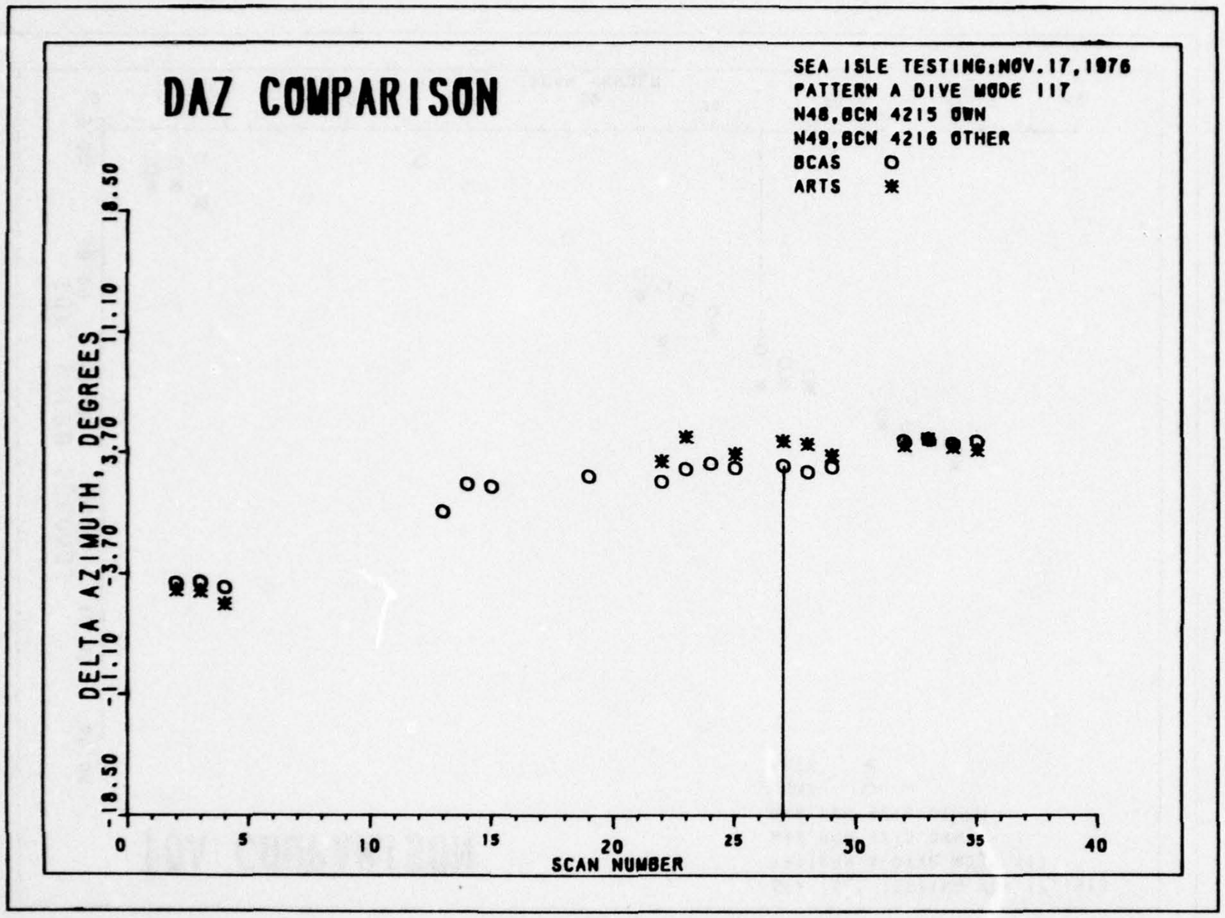


FIGURE 5.16-35

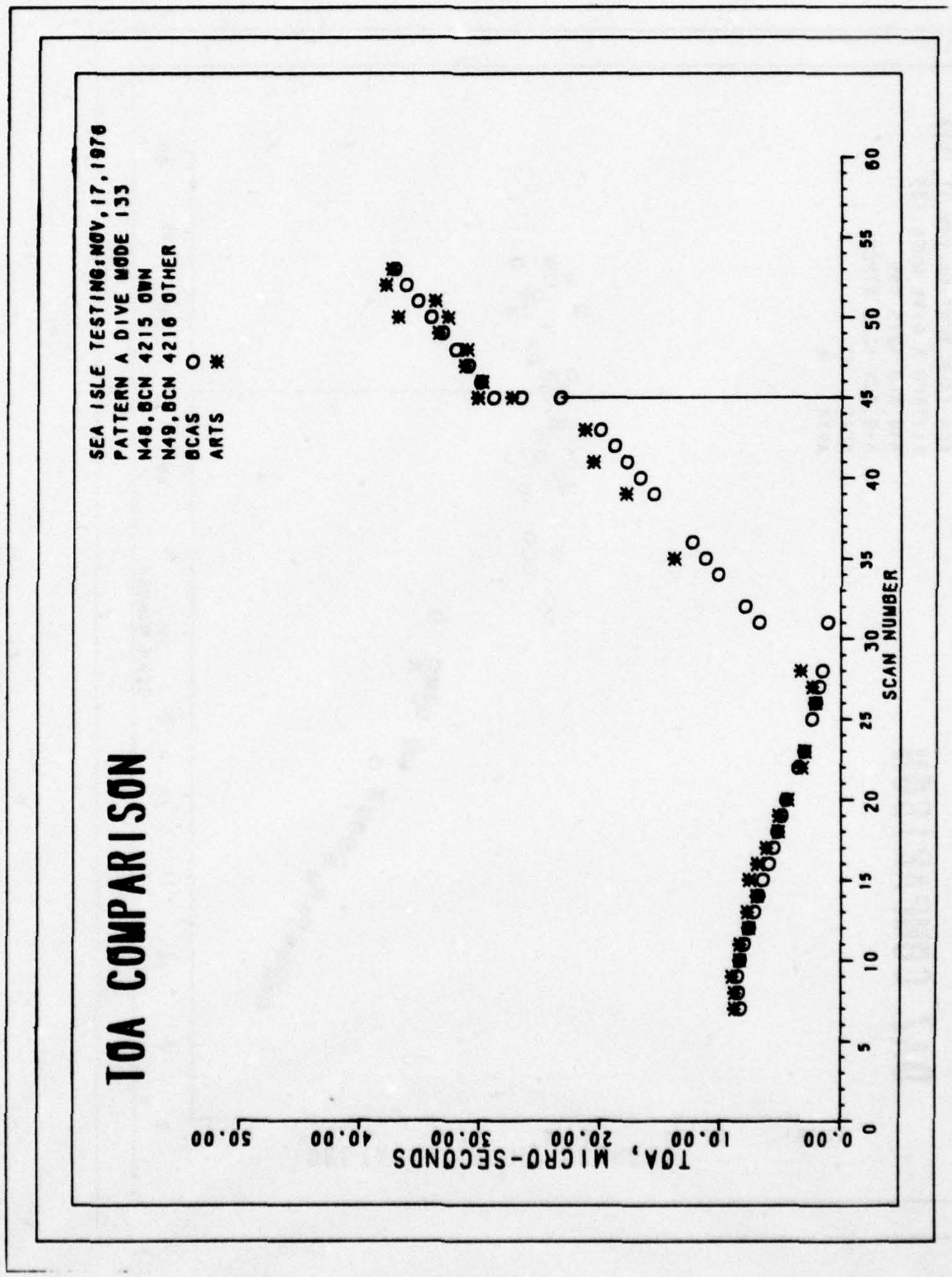


FIGURE 5.16-36

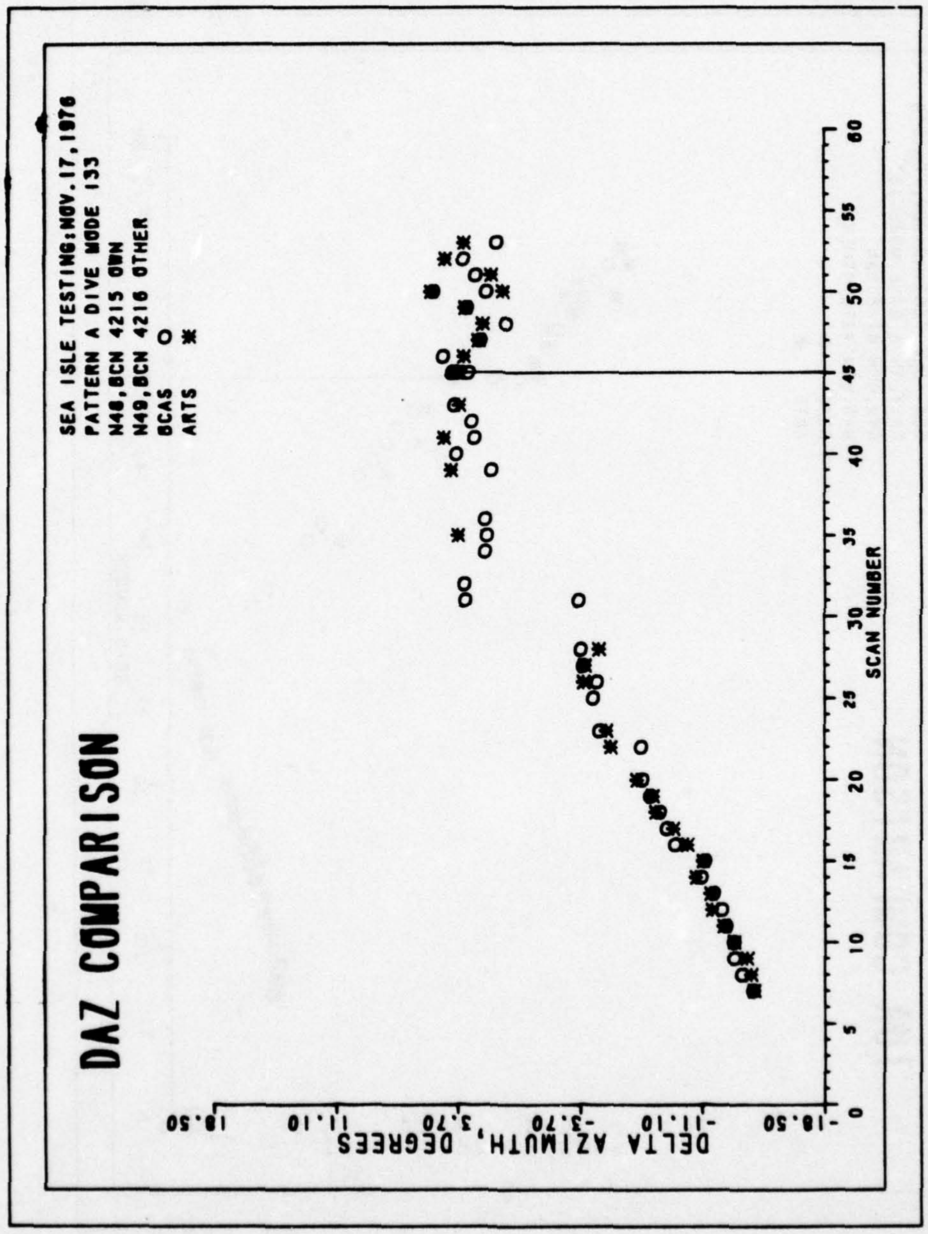


FIGURE 5.16-37

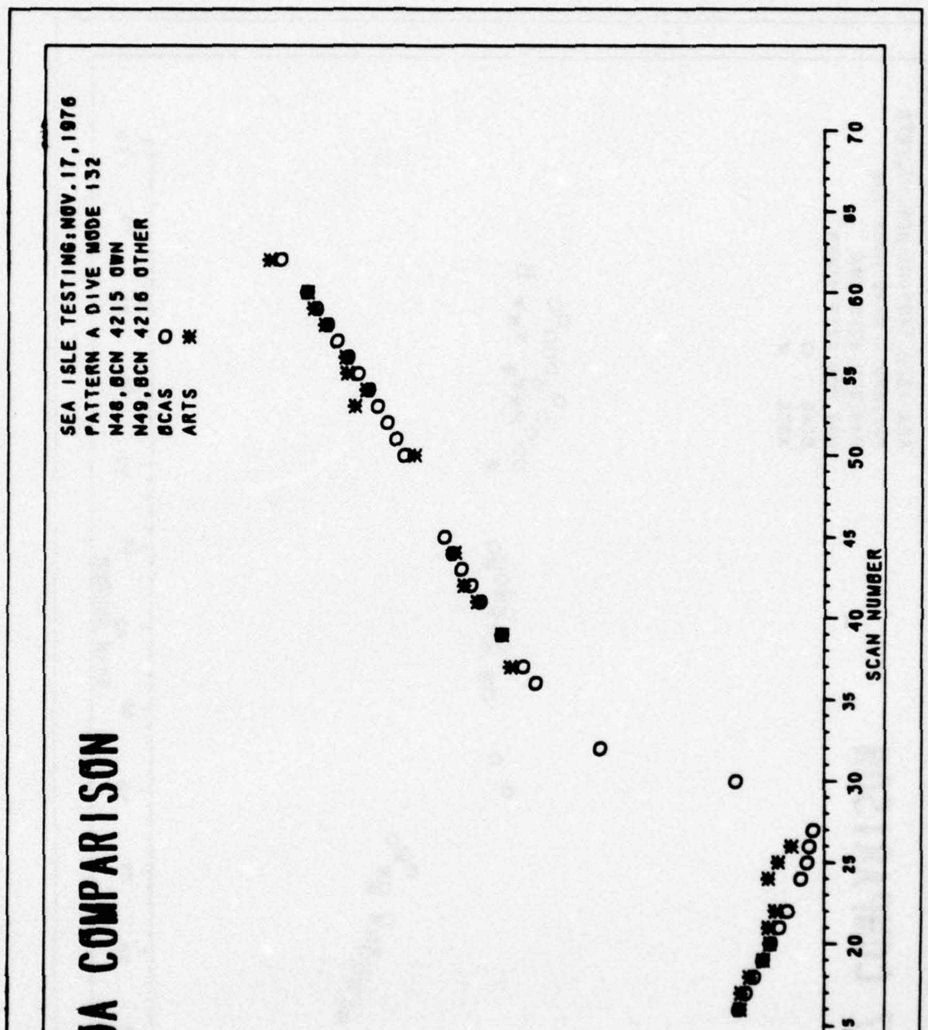


FIGURE 5.16-38

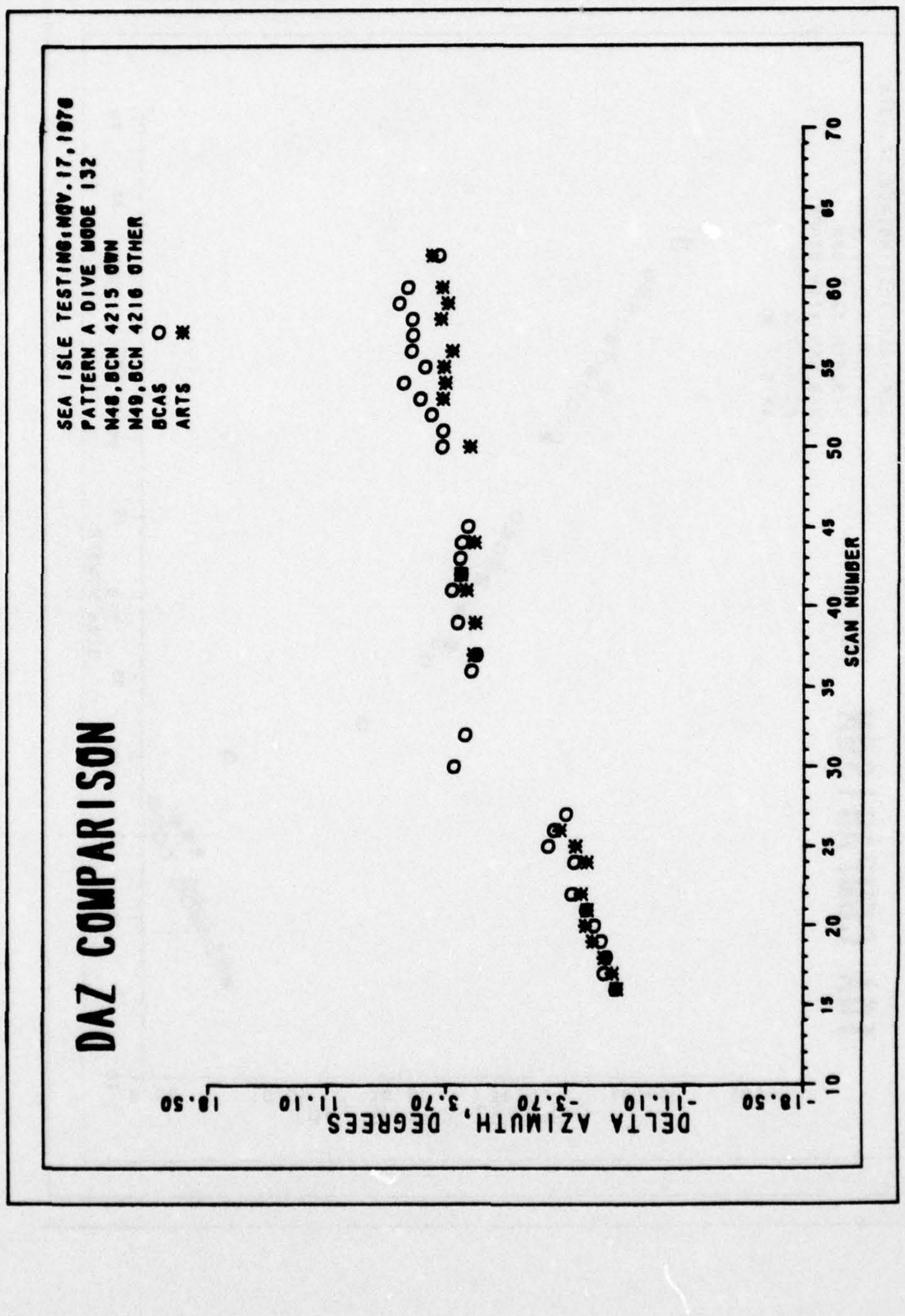


FIGURE 5.16-39

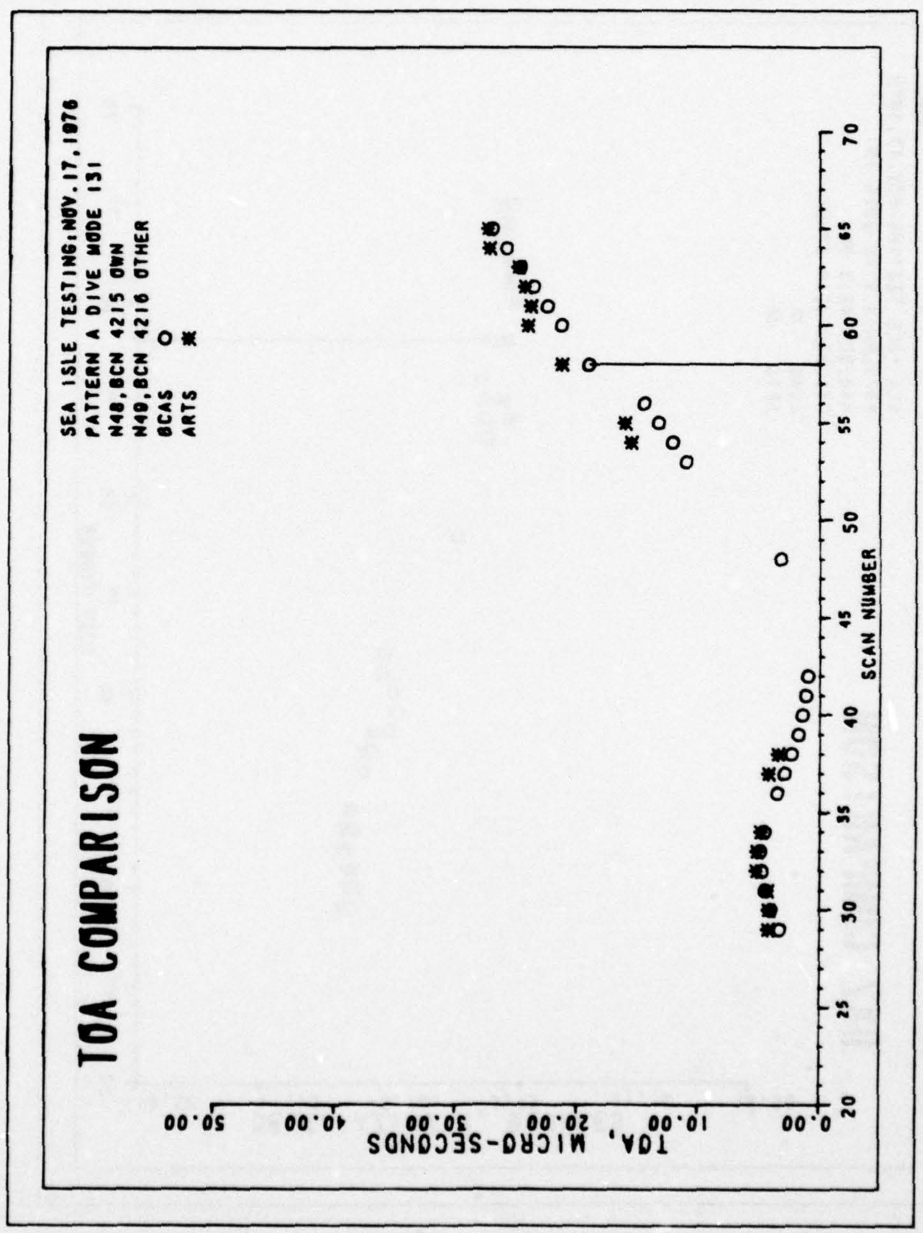


FIGURE 5.16-40

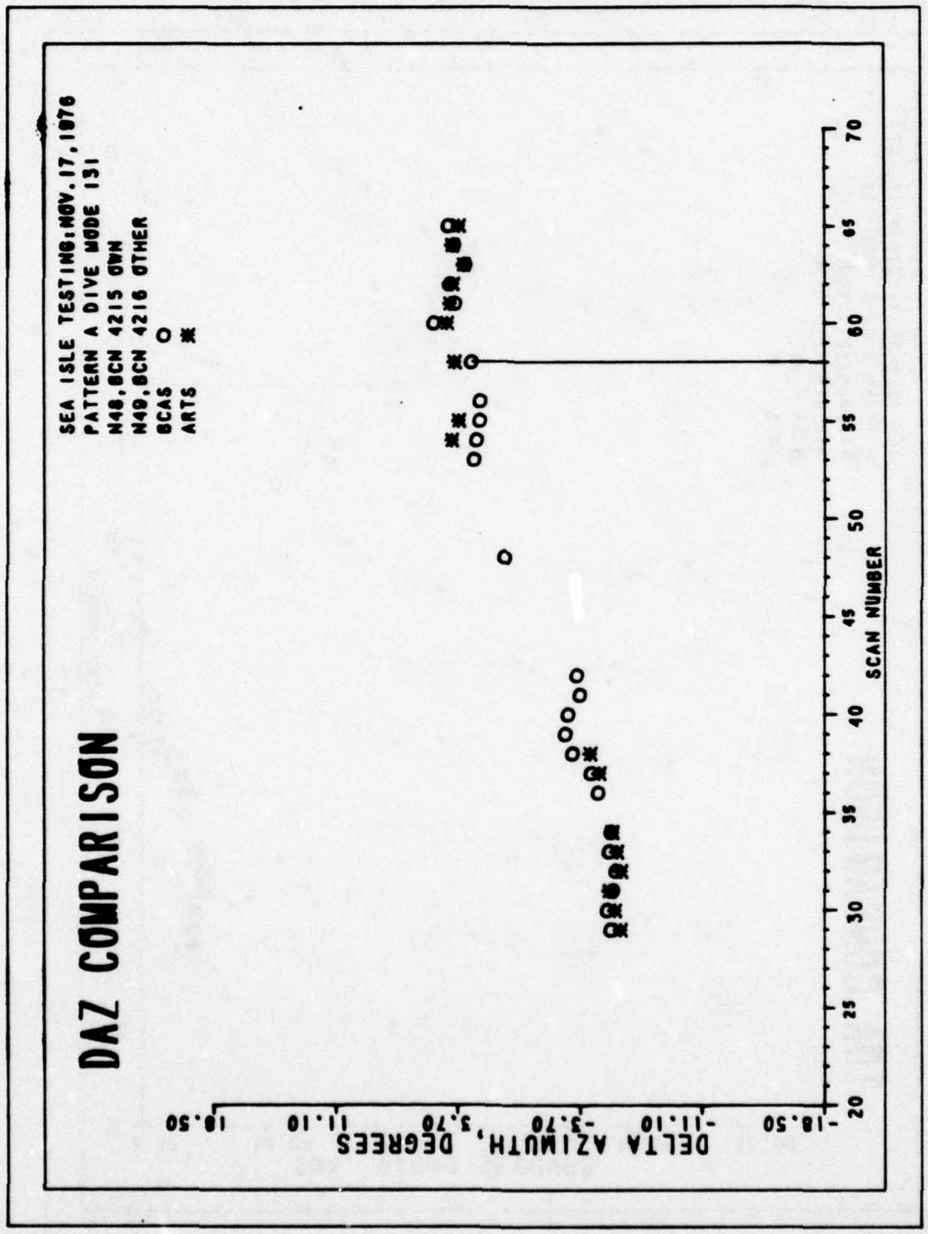


FIGURE 5.16-41

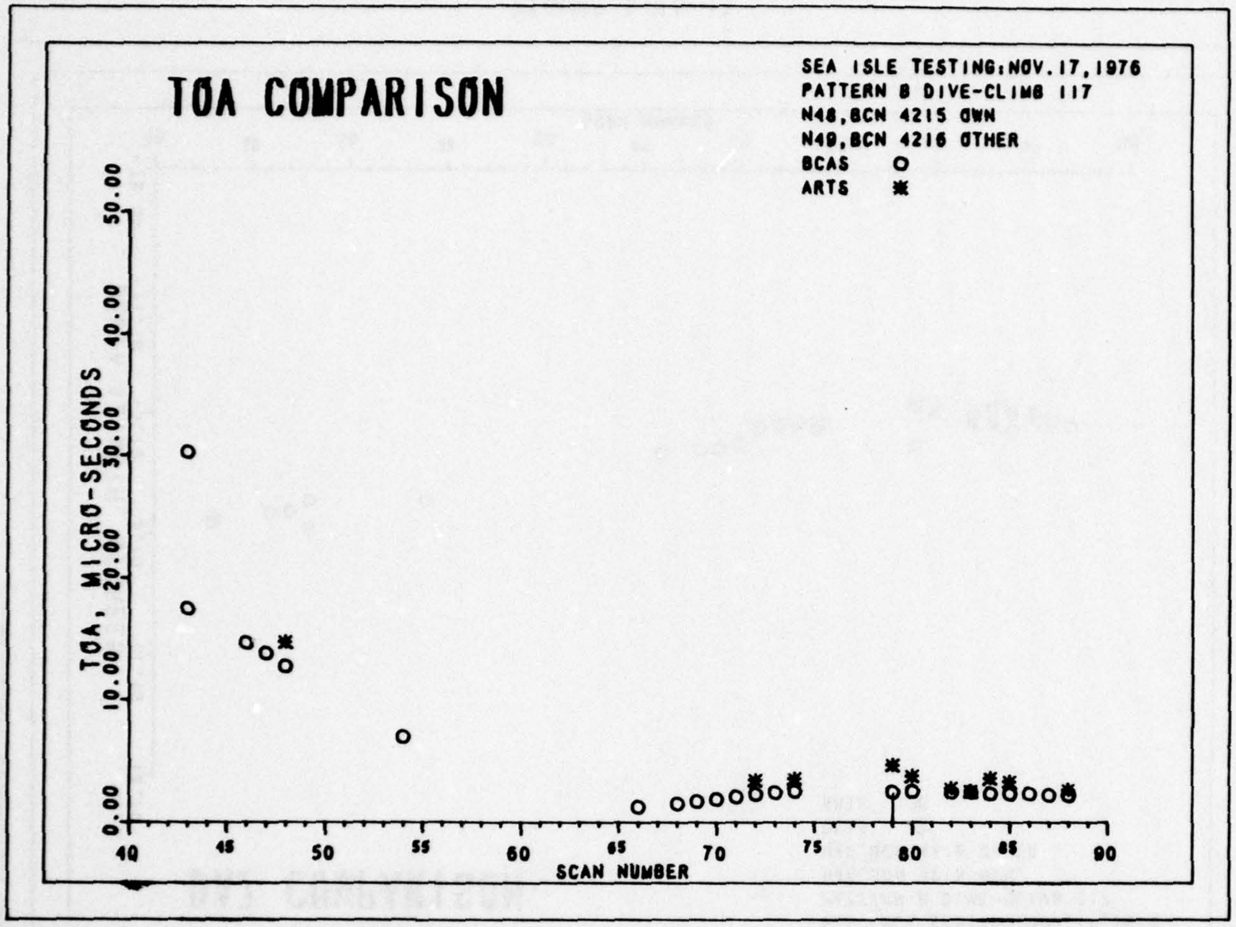


FIGURE 5.16-42

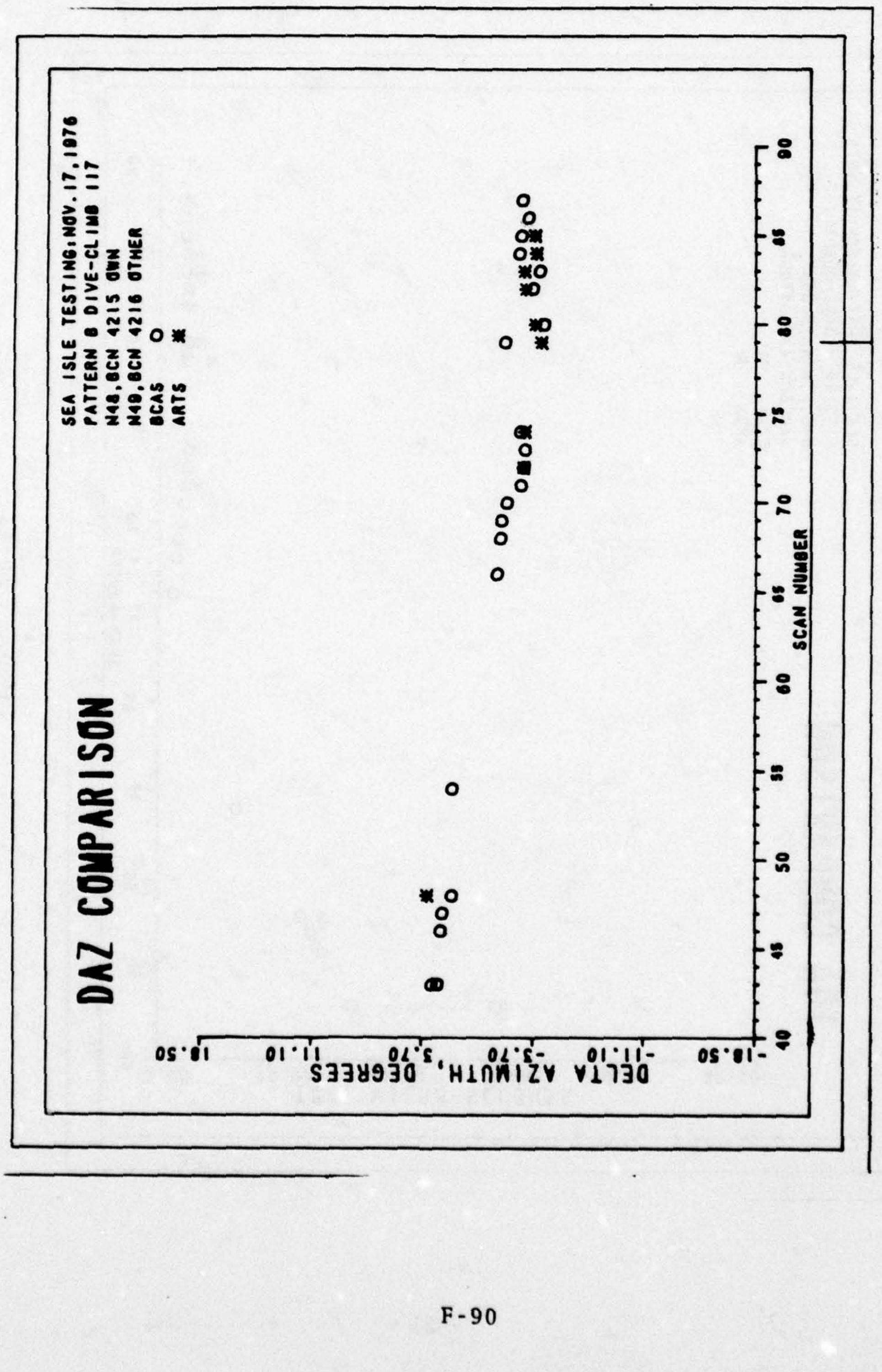


FIGURE 5.16-43

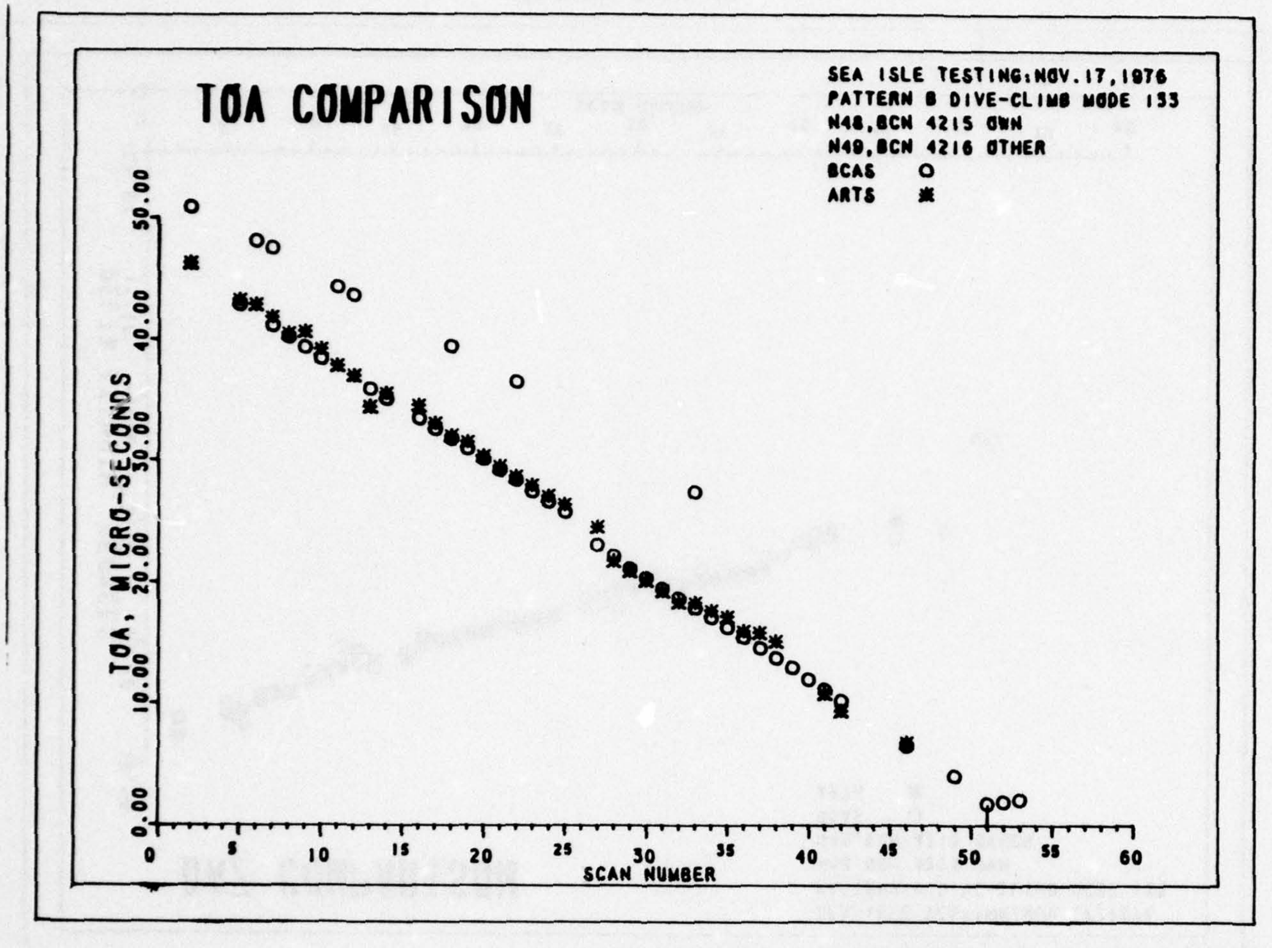


FIGURE 5.16-44

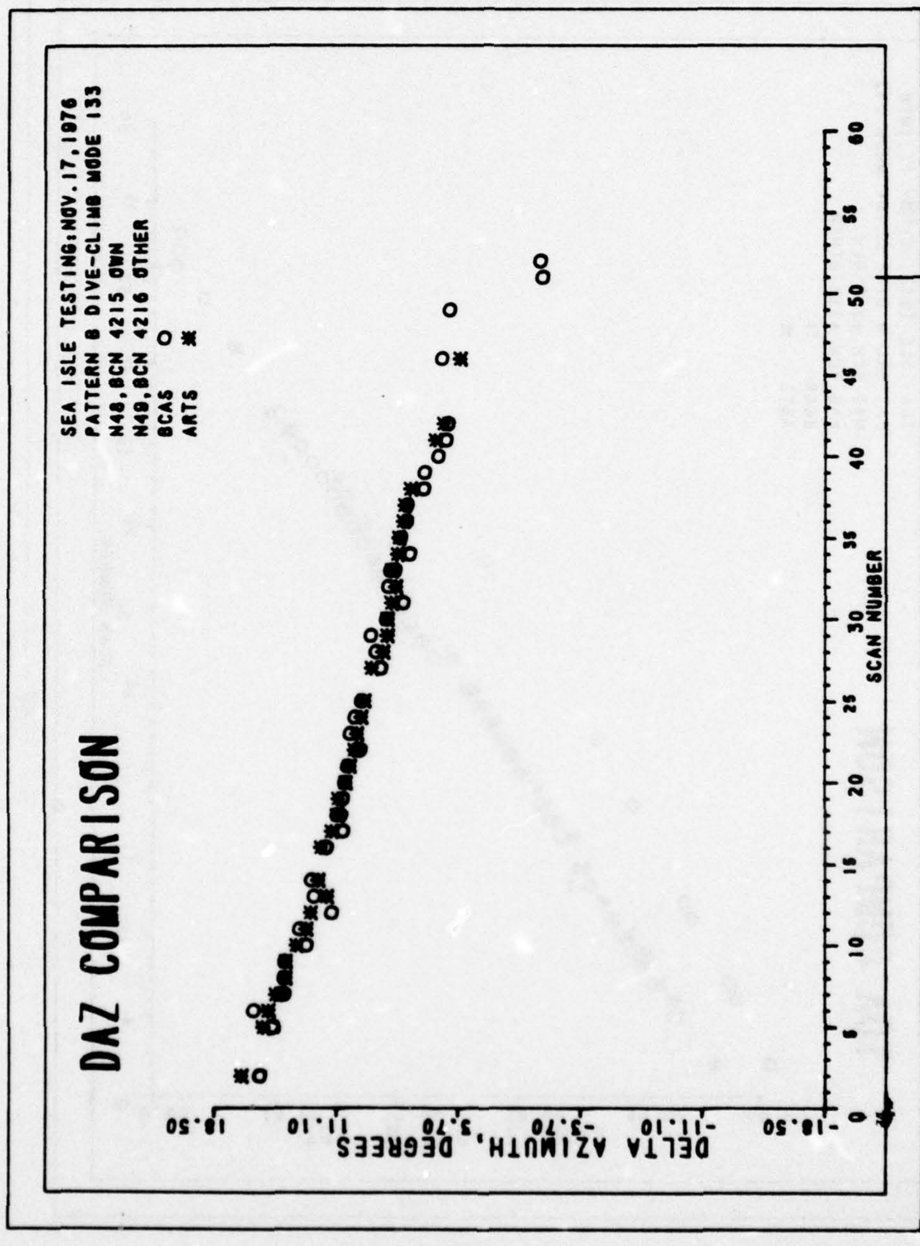


FIGURE 5.16-45

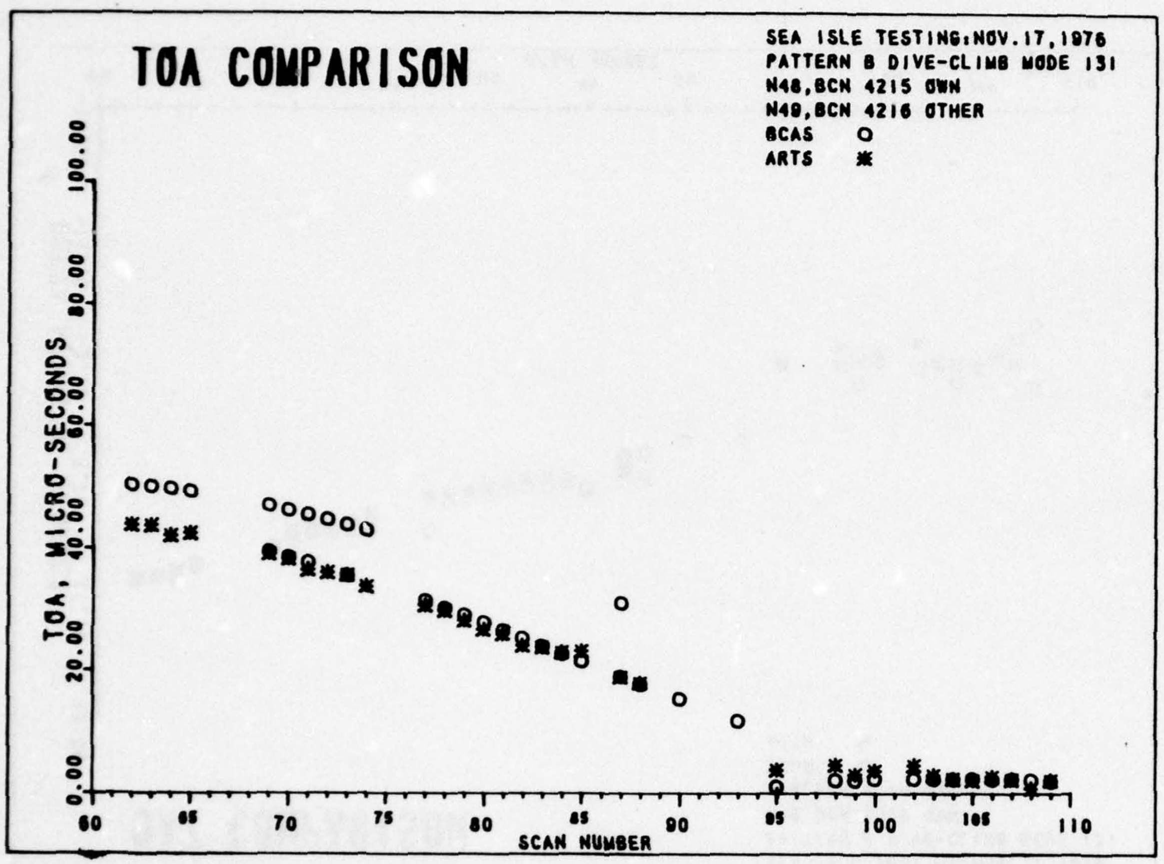


FIGURE 5.16-46

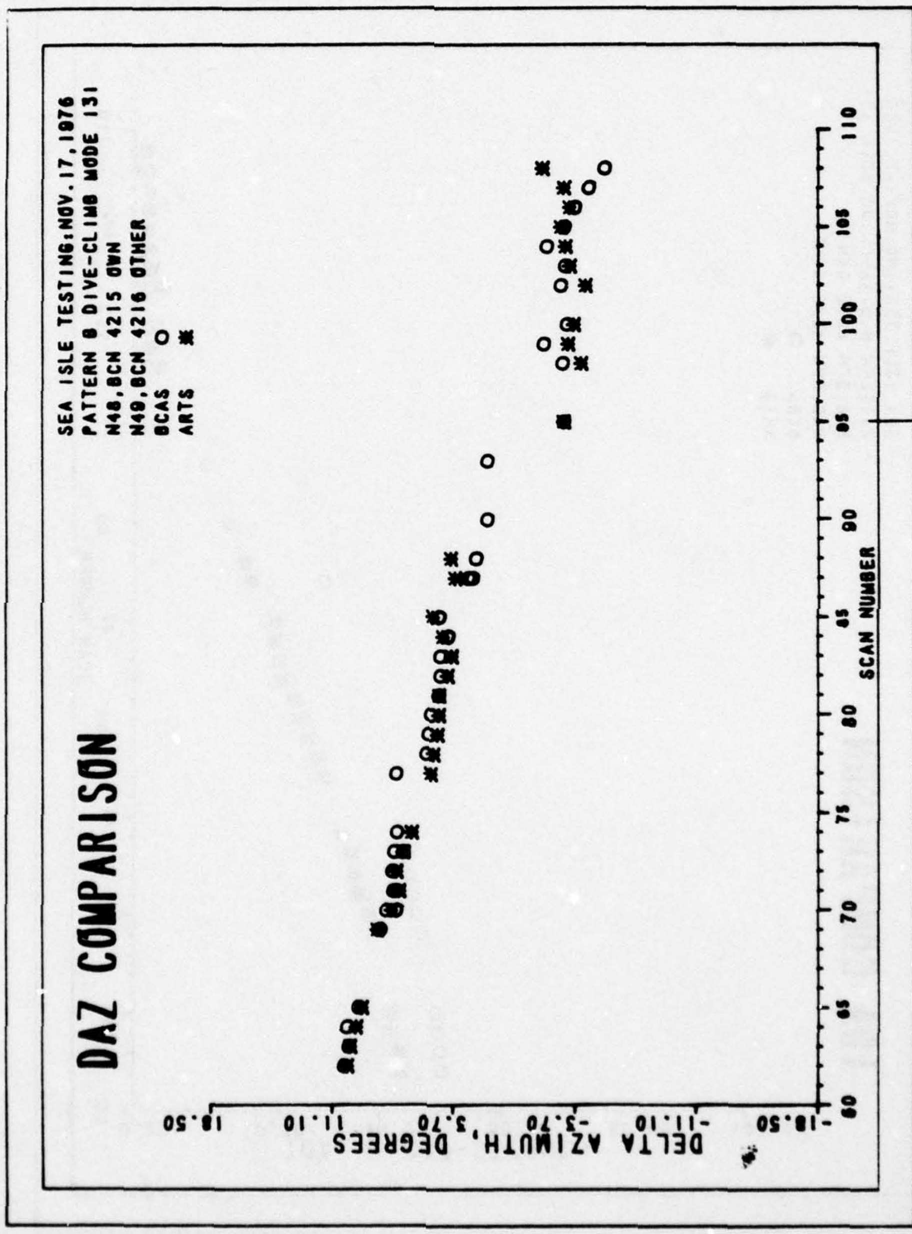


FIGURE 5.16-47

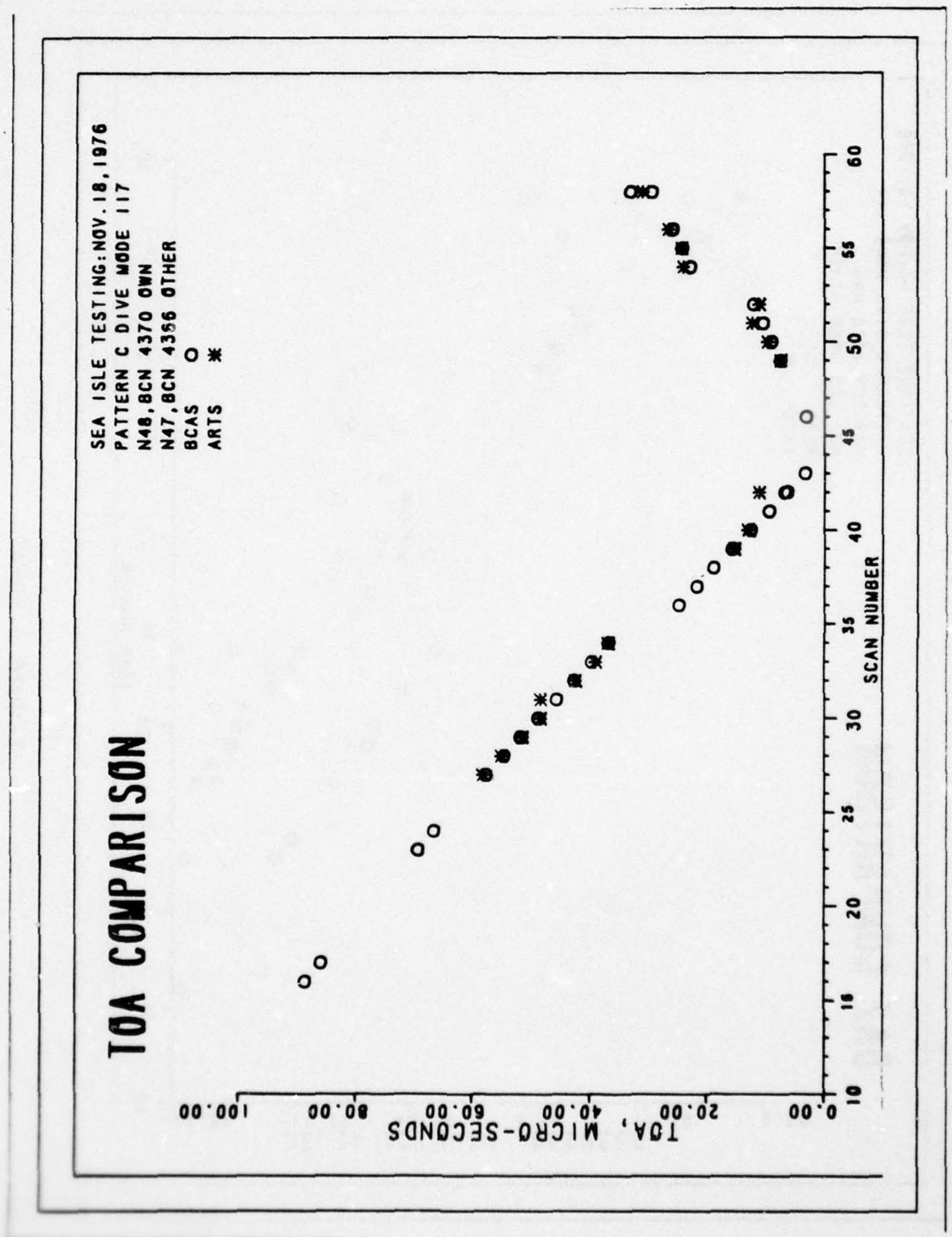


FIGURE 5.16-48

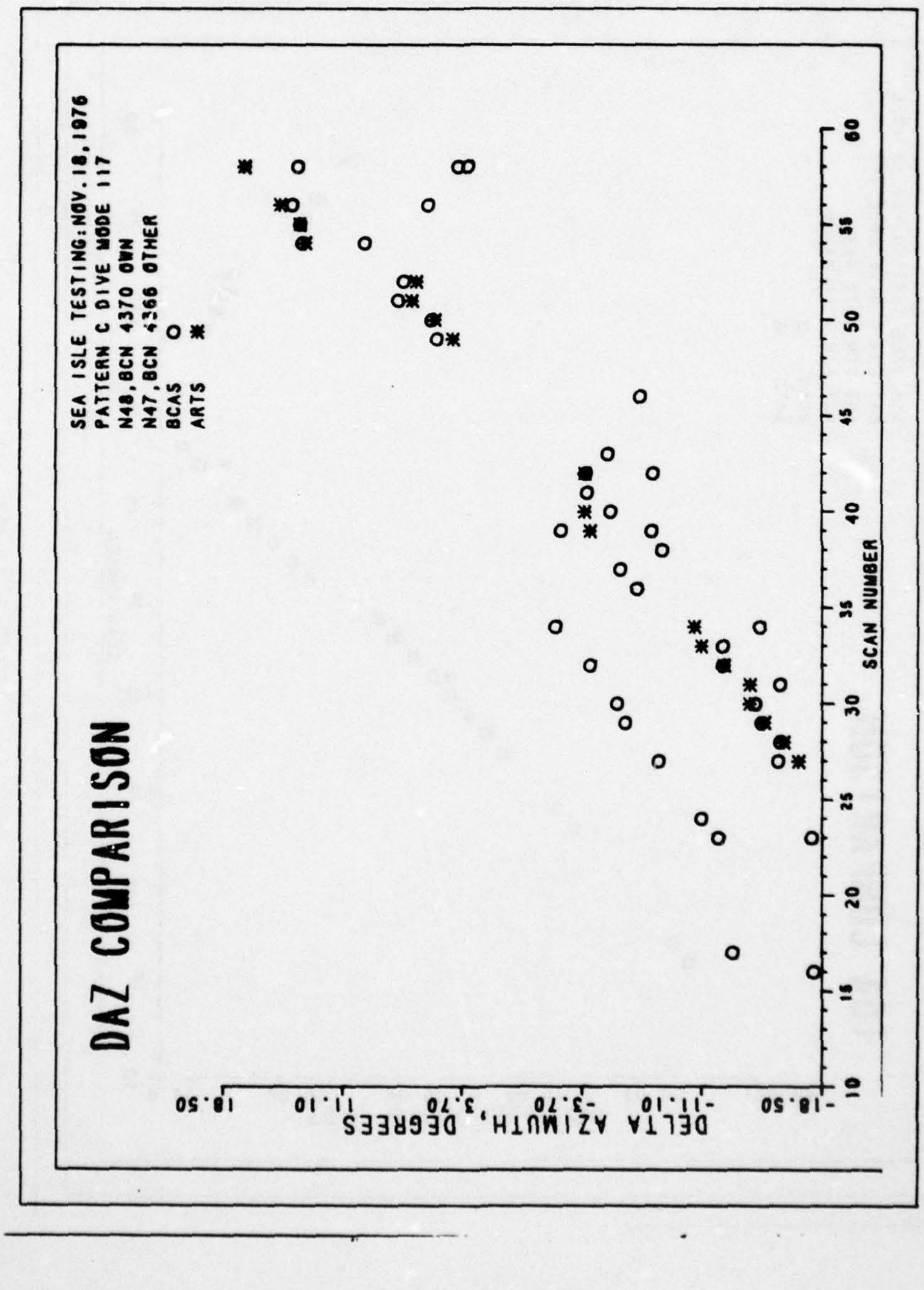


FIGURE 5.16-49

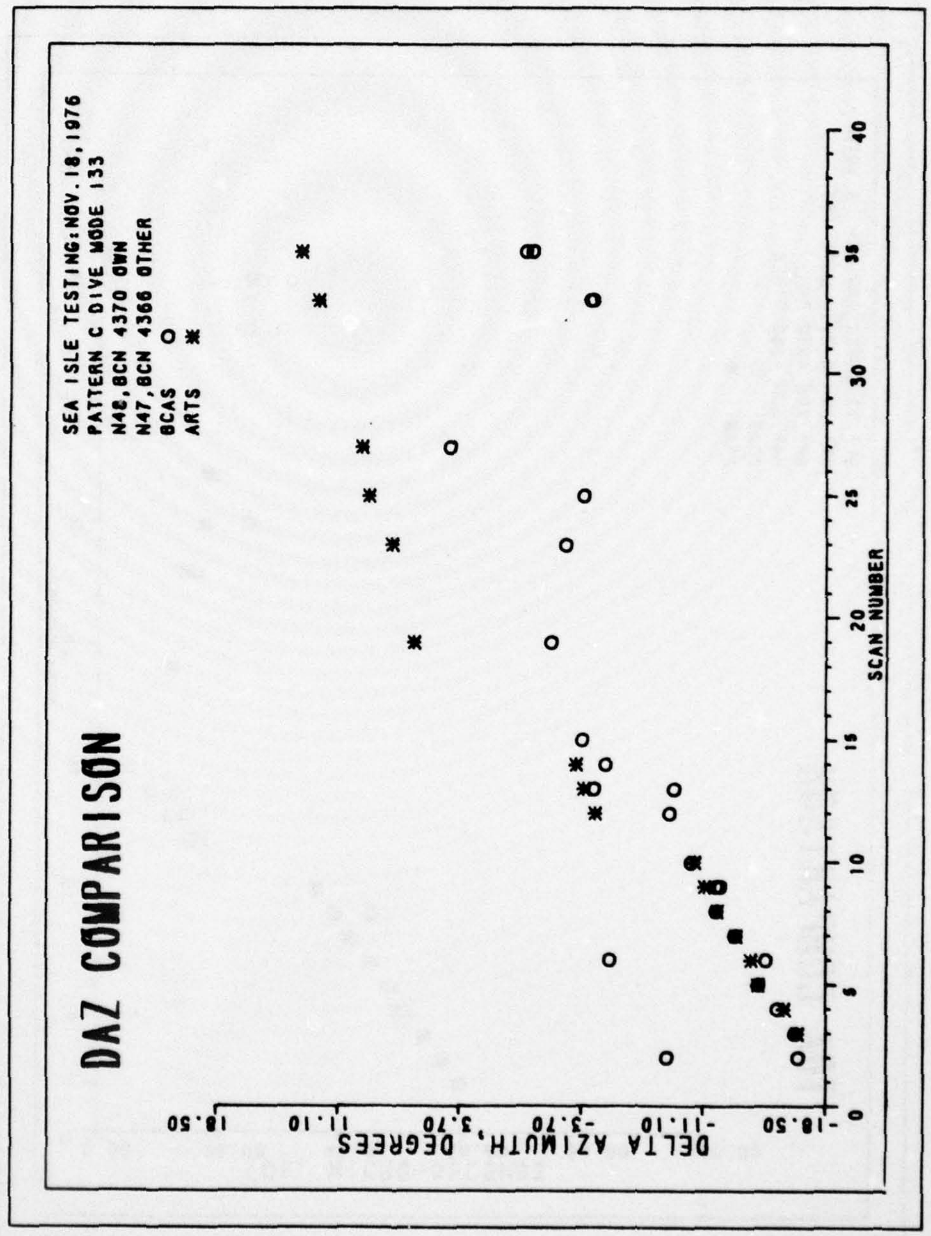


FIGURE 5.16-50

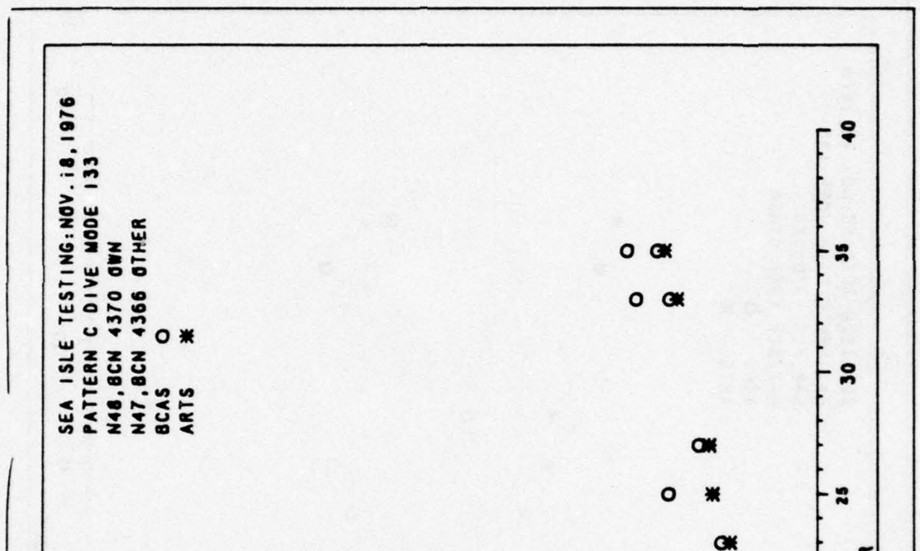


FIGURE 5.16-51

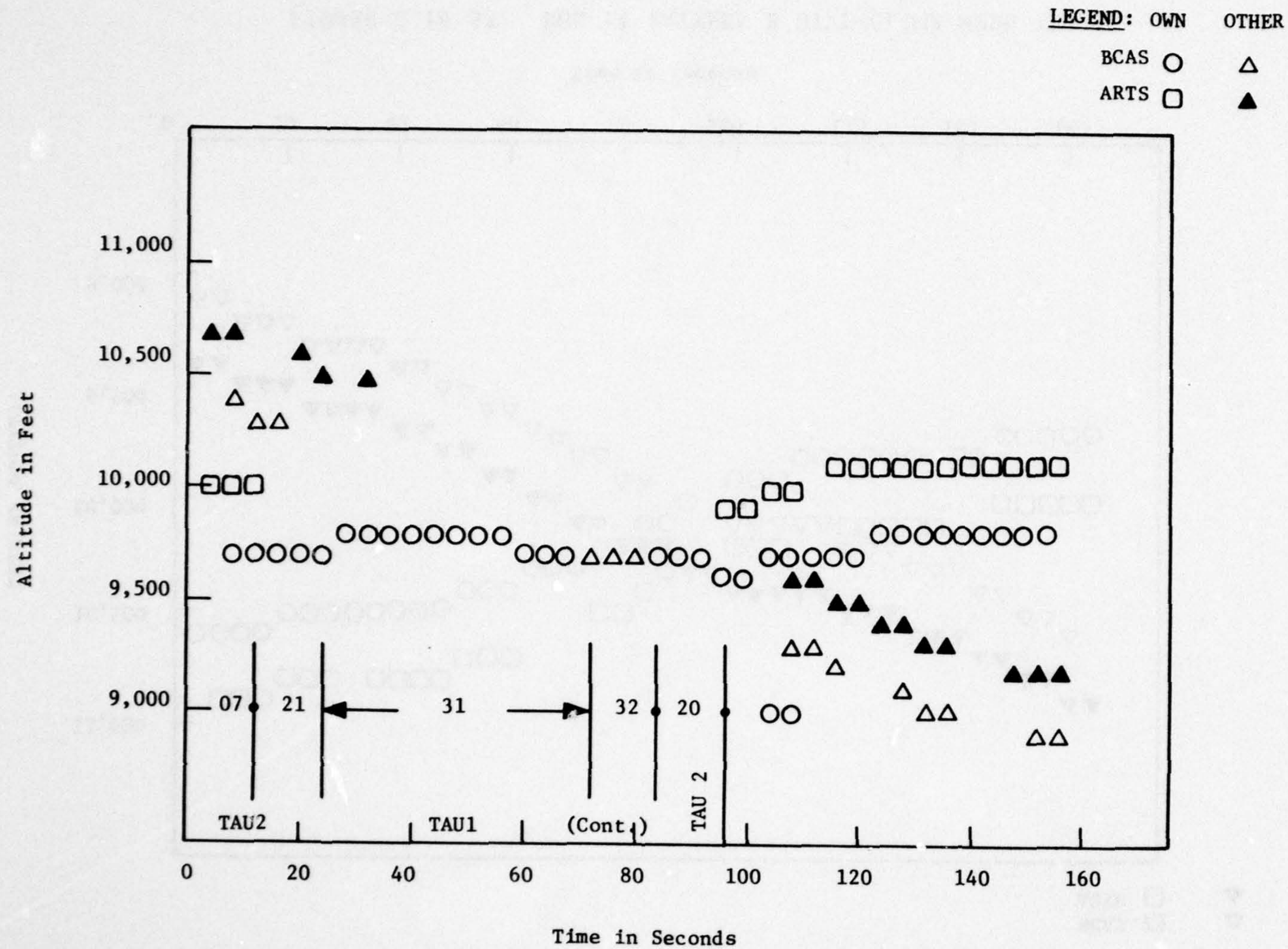


FIGURE 5.16-52. RUN 1 PATTERN A DIVE MODE I 17

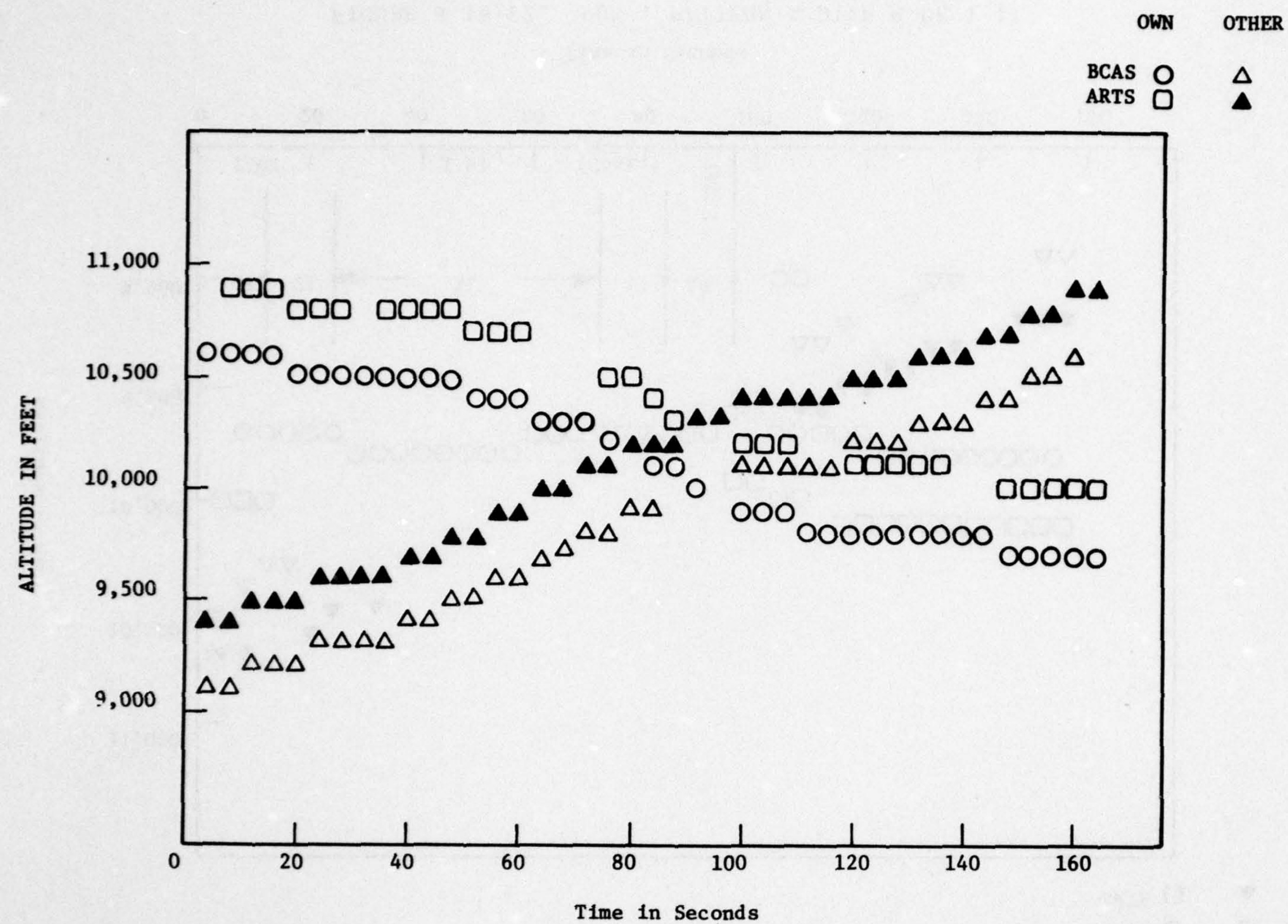


FIGURE 5.16-53. RUN 11 PATTERN B DIVE-CLIMB MODE I33

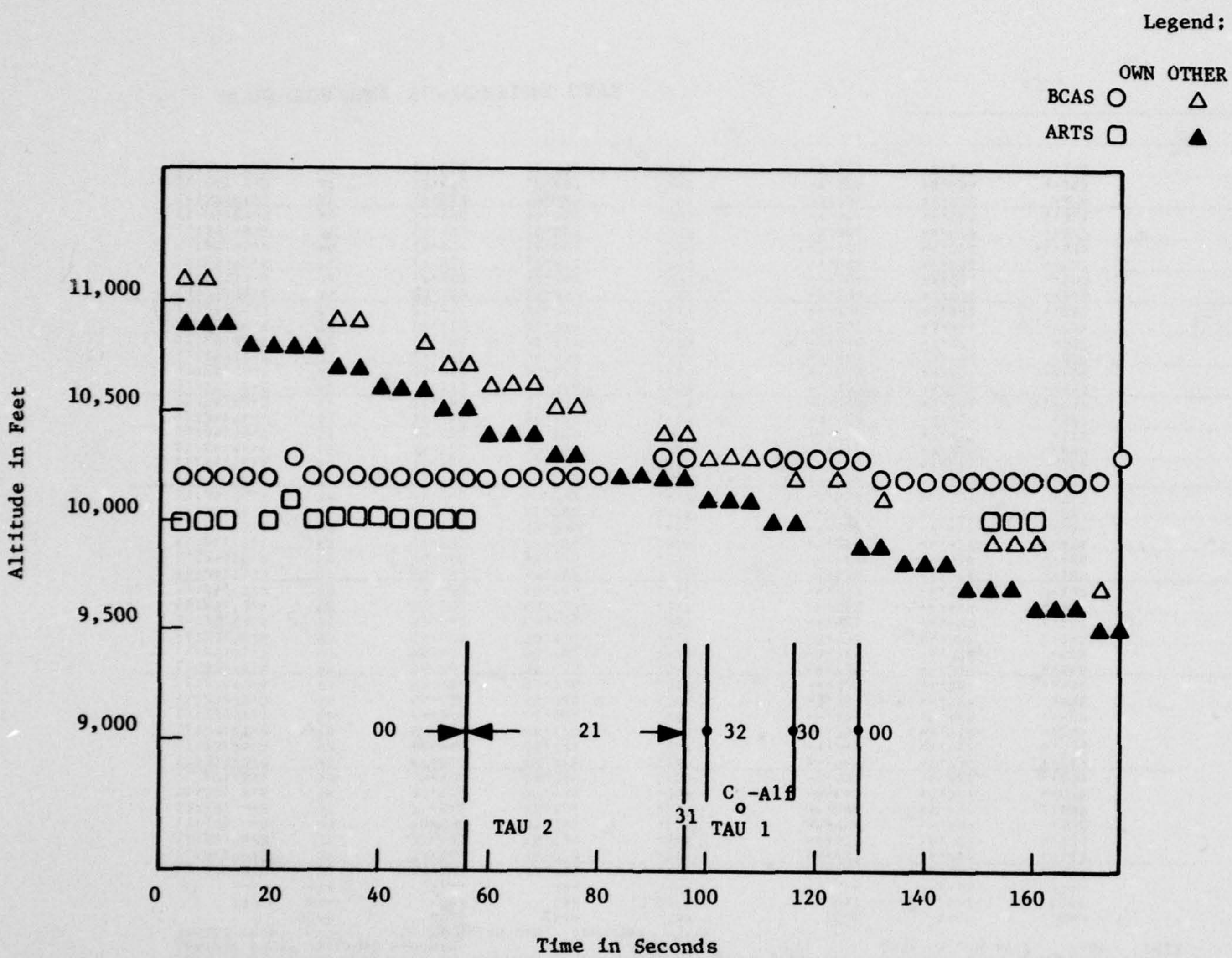


FIGURE 5.16-54. RUN 17 PATTERN C DIVE MODE I17

TABLE 5.3-1

TOA/DAZ ERROR ANALYSIS PROGRAM
TARGET CODE: 0777 RUN [illegible]3 LCAS 045 11/9/76 ASR-4 DATE 24 JAN 1977 PAGE 0003

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
11:22:49.0	33	80.050	79.599	.451	-6.163	-6.380	.217
11:22:52.9	34	78.590	78.079	.511	-6.438	-6.290	-.148
11:22:56.8	35	77.090	76.634	.456	-6.633	-6.099	-.734
11:23: .7	36	75.550	75.146	.404	-5.784	-5.884	.100
11:23: 4.6	37	74.040	73.706	.334	-4.592	-5.631	1.039
11:23: 8.6	38	72.500	72.136	.364	-5.449	-5.371	-.078
11:23:16.4	40	69.400	68.995	.405	-4.999	-4.868	-.131
11:23:20.3	41	67.860	67.376	.484	-4.949	-4.730	-.219
11:23:24.2	42	66.280	65.779	.501	-4.949	-4.619	-.330
11:23:28.2	43	64.650	64.175	.475	-4.757	-4.512	-.245
11:23:32.1	44	63.070	62.666	.404	-4.878	-4.449	-.429
11:23:39.9	46	60.030	59.680	.350	-3.367	-4.358	.991
11:23:43.8	47	58.450	58.136	.314	-4.708	-4.306	-.402
11:23:47.8	48	56.940	56.573	.367	-4.735	-4.339	-.396
11:23:51.7	49	55.490	55.052	.438	-3.774	-4.372	.598
11:23:55.6	50	54.000	53.565	.435	-4.532	-4.391	-.141
11:23:59.5	51	52.540	52.151	.389	-4.631	-4.430	-.201
11:24: 3.4	52	51.100	50.723	.377	-4.515	-4.458	-.057
11:24: 7.3	53	49.600	49.328	.272	-4.213	-4.475	.262
11:24:11.3	54	48.140	47.825	.315	-4.631	-4.471	-.160
11:24:15.2	55	46.660	46.329	.331	-4.872	-4.456	-.416
11:24:19.1	56	45.230	44.854	.376	-5.054	-4.428	-.626
11:24:23.0	57	43.800	43.386	.414	-4.466	-4.412	-.054
11:24:26.9	58	42.430	41.982	.448	-4.158	-4.372	.214
11:24:30.9	59	41.040	40.593	.447	-3.983	-4.302	.319
11:24:38.7	61	38.240	38.011	.229	-4.246	-4.136	-.110
11:24:42.6	62	36.900	36.619	.281	-4.202	-4.034	-.168
11:24:46.6	63	35.520	35.167	.353	-4.252	-3.959	-.293
11:24:50.5	64	34.220	33.829	.391	-3.774	-3.890	.116
11:24:54.4	65	32.880	32.421	.459	-3.439	-3.816	.377
11:24:58.3	66	31.530	31.102	.428	-5.048	-3.761	-1.287
11:25: 2.2	67	30.170	29.766	.404	-4.125	-3.710	-.415
11:25:14.0	70	26.220	25.891	.329	-4.279	-3.654	-.625
11:25:17.9	71	24.970	24.634	.336	-3.461	-3.696	.235
11:25:21.9	72	23.680	23.277	.403	-3.686	-3.773	.087
11:25:25.8	73	22.430	21.975	.455	-3.950	-3.856	-.094
11:25:29.7	74	21.210	20.799	.411	-4.202	-3.921	-.281
11:25:33.6	75	20.020	19.660	.360	-4.136	-3.971	-.165
11:25:37.6	76	18.950	18.559	.391	-4.504	-4.001	-.503
11:25:41.5	77	17.910	17.570	.340	-4.598	-4.031	-.567
11:25:45.4	78	16.930	16.601	.329	-5.707	-4.071	-1.636
11:25:49.4	79	15.990	15.612	.378	-4.356	-4.079	-.277
11:25:53.3	80	14.990	14.609	.381	-4.356	-4.045	-.311
11:25:57.2	81	14.010	13.629	.381	-3.724	-4.002	.278
11:26: 1.2	82	13.090	12.637	.453	-4.175	-3.986	-.189
11:26: 5.1	83	12.200	11.792	.408	-3.801	-3.943	.142

BCAS-TOA/DAZ SUPPORTING DATA

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0004

TARGET CODE: 0777 RUN [illegible]LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:26: 9.0	84	11.400	11.001	.399	-3.752	-3.916	.164
11:26:12.9	85	10.540	10.253	.287	-4.329	-3.883	-.446
11:26:36.5	91	7.020	6.780	.240	-3.983	-3.709	-.274
11:26:40.4	92	6.590	6.321	.269	-4.120	-3.619	-.501
11:26:48.3	94	5.710	5.504	.206	-3.400	-3.402	.002
11:27: .1	97	4.700	4.477	.223	-3.389	-3.184	-.205
11:27: 4.0	98	4.430	4.198	.232	-3.444	-3.157	-.287
11:27:15.8	101	3.770	3.588	.182	-3.593	-3.241	-.352
11:27:19.7	102	3.640	3.449	.191	-4.021	-3.376	-.645
11:27:23.6	103	3.520	3.314	.206	-3.642	-3.467	-.175
11:27:27.6	104	3.340	3.211	.129	-4.114	-3.544	-.570
11:27:31.5	105	3.280	3.069	.211	-3.631	-3.563	-.068
11:27:35.4	106	3.130	2.957	.173	-3.323	-3.598	.275
11:27:39.3	107	3.020	2.815	.205	-3.593	-3.617	.024
11:27:43.3	108	2.870	2.710	.160	-3.686	-3.630	-.056
11:27:47.2	109	2.750	2.605	.145	-4.197	-3.605	-.592
11:27:51.1	110	2.620	2.462	.158	-4.005	-3.556	-.449
11:27:59.0	112	2.430	2.270	.160	-3.829	-3.479	-.350
11:28: 2.9	113	2.360	2.150	.210	-4.252	-3.430	-.822
11:28: 6.8	114	2.180	2.059	.121	-3.686	-3.389	-.297
11:28:10.8	115	2.100	1.975	.125	-3.208	-3.332	.124
11:28:14.7	116	2.010	1.887	.123	-3.609	-3.272	-.337
11:28:22.5	118	1.880	1.739	.141	-3.571	-3.147	-.424
11:28:26.5	119	1.750	1.655	.095	-3.527	-3.076	-.451
11:28:34.3	121	1.710	1.521	.189	-3.505	-3.031	-.474
11:28:38.2	122	1.640	1.477	.163	-3.378	-3.035	-.343
11:28:42.2	123	1.550	1.429	.121	-3.395	-3.039	-.356
11:28:46.1	124	1.500	1.387	.113	-3.274	-3.024	-.250
11:28:50.1	125	1.560	1.345	.215	-3.340	-3.017	-.323
11:28:54.0	126	1.420	1.322	.098	-3.318	-3.029	-.289
11:28:57.9	127	1.410	1.288	.122	-3.318	-3.054	-.264
11:29: 1.8	128	1.420	1.258	.162	-3.922	-3.069	-.853

DAZ MEAN:	-.213	DAZ S.D.:	.403	N= 78	SUM= -16.577	SUM OF SQUARES=	16.012
TOA MEAN:	.304	TOA S.D.:	.121	N= 78	SUM= 23.736	SUM OF SQUARES=	8.346

TØA/DAZ ERRØR ANALYSIS PRØGRAM DATE 24 JAN 1977 PAGE 0005

TARGET CØDE: 0777 RUN #4 LCAS 045 11/9/76 ASR-4

TIME	SCAN NØ.	BCAS TØA	EAIR TØA	TØA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:34: 4.2	11	4.070	3.867	.203	-3.005	-3.408	.403
11:34: 8.1	12	4.500	4.295	.205	-3.115	-3.361	.246
11:34:12.0	13	5.120	4.870	.250	-3.554	-3.340	-.214
11:34:15.9	14	5.840	5.557	.283	-3.027	-3.306	.279
11:34:19.9	15	6.740	6.399	.341	-3.505	-3.314	-.191
11:34:31.6	18	10.650	10.212	.438	-3.779	-3.397	-.382
11:34:35.6	19	12.430	12.001	.429	-3.181	-3.477	.296
11:34:39.5	20	14.410	14.000	.410	-3.719	-3.570	-.149
11:34:43.4	21	16.560	16.186	.374	-3.911	-3.667	-.244
11:34:47.3	22	18.890	18.438	.452	-3.917	-3.735	-.182
11:34:51.3	23	21.460	20.981	.479	-4.208	-3.814	-.394
11:34:55.2	24	23.990	23.588	.402	-4.180	-3.890	-.290
11:34:59.1	25	26.690	26.287	.403	-4.257	-3.929	-.328
11:35: 7.0	27	32.240	31.759	.481	-4.016	-4.012	-.004
11:35:10.9	28	35.080	34.683	.397	-4.400	-4.071	-.329
11:35:14.8	29	37.970	37.541	.429	-4.076	-4.130	.054
11:35:18.8	30	40.890	40.452	.438	-4.455	-4.168	-.287
11:35:30.5	33	49.750	49.291	.459	-4.241	-4.074	-.167
11:35:34.5	34	52.730	52.260	.470	-3.994	-4.038	.044
11:35:38.4	35	55.690	55.215	.475	-4.224	-4.008	-.216
11:35:42.3	36	58.800	58.343	.457	-3.999	-4.018	.019
11:35:46.2	37	61.780	61.392	.388	-4.158	-4.029	-.129
11:35:50.2	38	64.910	64.502	.408	-3.708	-4.075	.367
11:35:54.1	39	67.950	67.468	.482	-4.356	-4.138	-.218
11:35:58.0	40	71.050	70.688	.362	-4.592	-4.195	-.397
11:36: 1.9	41	74.210	73.743	.467	-4.263	-4.303	.040
11:36: 5.8	42	77.260	76.716	.544	-4.763	-4.464	-.299
11:36: 9.8	43	80.440	79.926	.514	-4.279	-4.699	.420
11:36:17.6	45	86.680	86.228	.452	-5.301	-5.235	-.066
11:36:21.6	46	89.800	89.309	.491	-5.982	-5.515	-.467
11:36:25.5	47	92.960	92.421	.539	-5.773	-5.785	.012
11:36:29.4	48	96.030	95.592	.438	-6.147	-6.107	-.040
11:36:33.3	49	99.120	98.688	.432	-6.828	-6.399	-.429

DAZ MEAN: -.098 DAZ S.D.: .254 N= 33 SUM= -3.242 SUM ØF SQUARES= 2.381

TØA MEAN: .418 TØA S.D.: .084 N= 33 SUM= 13.792 SUM ØF SQUARES= 5.988

TBA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0006
TARGET CODE: 0777 RUN 5 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TBA	EAIR TBA	TBA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:45:47.1	17	98.680	98.404	.276	-9.223	-9.259	.036
11:45:51.1	18	97.150	96.866	.284	-8.833	-8.885	.052
11:45:55.0	19	95.650	95.304	.346	-9.025	-8.566	-.459
11:45:58.9	20	94.120	93.780	.340	-9.772	-8.292	-1.480
11:45:58.9	20	94.120			-7.004		
11:46: 2.8	21	92.600	92.194	.406	-8.427	-8.062	-.365
11:46: 6.7	22	91.080	90.663	.417	-8.075	-7.851	-.224
11:46:10.7	23	89.610	89.160	.450	-7.592	-7.681	.089
11:46:14.6	24	88.140	87.685	.455	-7.712	-7.510	-.202
11:46:18.5	25	86.610	86.281	.329	-7.504	-7.393	-.111
11:46:22.4	26	85.150	84.836	.314	-7.564	-7.283	-.281
11:46:26.4	27	83.670	83.288	.382	-7.147	-7.179	.032
11:46:30.3	28	82.190	81.831	.359	-7.504	-7.119	-.385
11:46:34.2	29	80.790	80.319	.471	-7.108	-7.232	.124
11:46:38.1	30	79.330	78.908	.422	-7.432	-7.400	-.032
11:46:42.0	31	77.880	77.500	.380	-7.943	-7.634	-.309
11:46:46.0	32	76.490	76.125	.365	-8.229	-7.921	-.308
11:46:49.9	33	75.110	74.795	.315	-8.229	-8.229	.000
11:46:53.8	34	73.700	73.425	.275	-8.657	-8.461	-.196
11:46:57.7	35	72.280	72.008	.272	-8.580	-8.506	-.074
11:47: 1.7	36	70.840	70.461	.379	-8.339	-8.456	.117
9:36:21.7	38	67.920			-8.828		
9:36:25.6	39	66.470			-8.959		
9:36:29.6	40	65.020			-8.416		
9:36:33.5	41	63.490			-8.734		
9:36:37.4	42	62.040			-7.646		
9:36:41.3	43	60.540			-7.476		
9:36:45.2	44	59.020			-7.586		
9:36:49.2	45	57.530			-7.224		
9:36:53.1	46	56.040			-8.383		
9:36:57.0	47	54.420			-7.575		
11:47:48.8	48	52.890	52.506	.384	-7.471	-7.127	-.344
11:47:52.7	49	51.480	51.032	.448	-6.498	-7.032	.534
11:47:56.6	50	49.860	49.565	.295	-6.465	-7.018	.553
11:48: 4.5	52	46.900	46.500	.400	-7.449	-7.005	-.444
11:48: 8.4	53	45.390	44.989	.401	-7.240	-7.064	-.176
11:48:12.3	54	43.950	43.485	.465	-6.729	-7.106	.377
11:48:20.2	56	40.900	40.505	.395	-7.191	-7.182	-.009
11:48:24.1	57	39.430	39.171	.259	-7.218	-7.215	-.003
11:48:28.0	58	37.950	37.639	.311	-7.608	-7.243	-.365
11:48:31.9	59	36.510	36.139	.371	-7.059	-7.229	.170
11:48:35.8	60	35.010	34.663	.347	-6.855	-7.191	.336
11:48:39.8	61	33.640	33.144	.496	-7.086	-7.161	.075
11:48:43.7	62	32.160	31.720	.440	-7.405	-7.122	-.283
11:48:47.6	63	30.760	30.400	.360	-7.163	-7.105	-.058
11:48:51.5	64	29.450	29.068	.382	-7.690	-7.062	-.628

TBA/DAZ ERROR ANALYSIS PROGRAM　　　　DATE 24 JAN 1977　　PAGE 0007

TARGET CODE: 0777　RUN 5　LCAS 045　11/9/76　ASR-4

TIME	SCAN NO.	BCAS TBA	EAIR TBA	TBA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:48:55.5	65	28.090	27.715	.375	-7.460	-7.021	-.439
11:48:59.4	66	26.680	26.416	.264	-6.850	-6.969	.119
11:49: 7.2	68	24.080	23.714	.366	-7.103	-6.836	-.267
11:49:11.2	69	22.830	22.401	.429	-6.828	-6.759	-.069
11:49:15.1	70	21.540	21.131	.409	-6.531	-6.698	.167
11:49:19.0	71	20.340	19.953	.387	-7.070	-6.623	-.447
11:49:23.0	72	19.140	18.803	.337	-6.669	-6.591	-.078
11:49:30.8	74	16.930	16.576	.354	-6.548	-6.566	.018
11:49:34.7	75	15.880	15.537	.343	-6.449	-6.555	.106
11:49:38.7	76	14.880	14.481	.399	-6.389	-6.546	.157
11:49:42.6	77	13.950	13.567	.383	-6.921	-6.513	-.408
11:49:46.5	78	13.070	12.752	.318	-6.636	-6.487	-.149
11:49:50.4	79	12.270	11.960	.310	-6.526	-6.453	-.073
11:49:54.3	80	11.520	11.300	.220	-6.768	-6.452	-.316
11:49:58.3	81	10.980	10.675	.305	-6.581	-6.482	-.099
11:50: 2.2	82	10.340	10.016	.324	-6.400	-6.491	.091
11:50: 6.1	83	9.730	9.441	.289	-6.416	-6.520	.104
11:50:10.1	84	9.200	8.918	.282	-6.509	-6.549	.040
11:50:14.0	85	8.720	8.425	.295	-6.482	-6.568	.086
11:50:17.9	86	8.300	7.994	.306	-6.570	-6.575	.005
11:50:21.8	87	7.790	7.527	.263	-6.389	-6.558	.169
11:50:25.8	88	7.390	7.103	.287	-6.295	-6.544	.249
11:50:29.7	89	6.960	6.695	.265	-6.751	-6.530	-.221
11:50:33.6	90	6.590	6.356	.234	-6.246	-6.510	.264
11:50:41.5	92	5.920	5.723	.197	-6.279	-6.490	.211
11:50:45.4	93	5.690	5.476	.214	-6.619	-6.474	-.145
11:50:49.3	94	5.430	5.227	.203	-6.515	-6.478	-.037
11:50:53.3	95	5.220	5.012	.208	-6.905	-6.485	-.420
11:50:57.2	96	5.030	4.808	.222	-6.119	-6.493	.374
11:51: 1.1	97	4.860	4.608	.252	-6.185	-6.489	.304
11:51: 5.1	98	4.640	4.422	.218	-6.454	-6.482	.028
11:51: 9.0	99	4.430	4.239	.191	-6.509	-6.474	-.035
11:51:12.9	100	4.320	4.070	.250	-5.922	-6.453	.531
11:51:16.8	101	4.110	3.925	.185	-6.400	-6.467	.067
11:51:20.8	102	3.950	3.791	.159	-6.636	-6.453	-.183
11:51:24.7	103	3.840	3.649	.191	-6.872	-6.456	-.416
11:51:28.6	104	3.710	3.530	.180	-6.691	-6.465	-.226
11:51:32.5	105	3.570	3.442	.128	-6.196	-6.489	.293
11:51:36.5	106	3.510	3.320	.190	-6.147	-6.495	.348
11:51:40.4	107	3.400	3.229	.171	-6.751	-6.511	-.240
11:51:44.3	108	3.310	3.146	.164	-6.658	-6.516	-.142
11:51:48.3	109	3.190	3.056	.134	-6.740	-6.509	-.231
11:51:52.2	110	3.120	2.962	.158	-6.411	-6.482	.071
11:51:56.1	111	3.040	2.849	.191	-6.515	-6.435	-.080
11:52: .0	112	2.970	2.772	.198	-7.663	-6.397	-1.266
11:52: .1	112	2.940	2.771	.169	-5.048	-6.397	1.349

TØA/DAZ ERRØR ANALYSIS PRØGRAM DATE 24 JAN 1977 PAGE 0008

TARGET CØDE: 0777 RUN 5 LCAS 045 11/9/76 ASR-4

TIME	SCAN NØ.	BCAS TØA	EAIR TØA	TØA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:52: 4.0	113	2.870	2.687	.183	-6.443	-6.402	-.041
11:52: 7.9	114	2.780	2.609	.171	-6.224	-6.363	.139
11:52:11.8	115	2.690	2.546	.144	-6.196	-6.365	.169
11:52:15.8	116	2.630	2.461	.169	-6.290	-6.318	.028
11:52:23.6	118	2.480	2.341	.139	-5.900	-6.284	.384
11:52:27.5	119	2.400	2.287	.113	-6.279	-6.288	.009
11:52:31.5	120	2.390	2.223	.167	-6.575	-6.282	-.293

DAZ MEAN: -.053 DAZ S.D.: .354 N= 88 SUM= -4.682 SUM ØF SQUARES= 11.151

TØA MEAN: .295 TØA S.D.: .098 N= 88 SUM= 25.994 SUM ØF SQUARES= 8.513

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0002
TARGET CODE: 0777 RUN 6 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:55:59.6	15	2.680	2.510	.170	-5.339	-5.227	-.112
11:56: 3.5	16	2.850	2.701	.149	-5.037	-5.302	.265
11:56: 7.4	17	3.020	2.879	.141	-5.125	-5.336	.211
11:56:11.4	18	3.250	3.089	.161	-5.268	-5.394	.126
11:56:15.3	19	3.530	3.284	.246	-5.674	-5.436	-.238
11:56:23.1	21	4.070	3.852	.218	-5.400	-5.564	.164
11:56:27.1	22	4.400	4.232	.168	-5.922	-5.622	-.300
11:56:31.0	23	4.870	4.623	.247	-6.059	-5.698	-.361
11:56:34.9	24	5.320	5.118	.202	-5.878	-5.824	-.054
11:56:38.9	25	5.980	5.713	.267	-5.916	-5.941	.025
11:56:42.8	26	6.670	6.416	.254	-5.779	-6.078	.299
11:56:46.7	27	7.450	7.218	.232	-6.152	-6.207	.055
11:56:50.6	28	8.380	8.087	.293	-6.125	-6.312	.187
11:56:54.5	29	9.440	9.116	.324	-6.581	-6.392	-.189
11:56:58.5	30	10.610	10.319	.291	-6.910	-6.497	-.413
11:57: 2.4	31	12.030	11.665	.365	-6.762	-6.608	-.154
11:57: 6.3	32	13.610	13.112	.498	-6.718	-6.721	.003
11:57:10.3	33	15.220	14.806	.414	-6.817	-6.835	.018
11:57:14.2	34	17.050	16.669	.381	-7.020	-6.922	-.098
11:57:22.1	36	21.290	20.836	.454	-7.075	-7.140	.065
11:57:26.0	37	23.580	23.066	.514	-7.339	-7.261	-.078
11:57:29.9	38	25.920	25.521	.399	-7.322	-7.377	.055
11:57:33.8	39	28.440	27.954	.486	-7.180	-7.415	.235
11:57:37.8	40	30.930	30.459	.471	-7.630	-7.466	-.164
11:57:45.6	42	36.190	35.691	.499	-7.482	-7.681	.199
11:57:49.5	43	38.800			-8.113		
11:57:53.5	44	41.490	41.038	.452	-8.152	-7.731	-.421
11:57:57.4	45	44.290	43.733	.557	-8.069	-7.796	-.273
11:58: 1.3	46	47.060	46.549	.511	-8.251	-7.844	-.407
11:58: 9.2	48	52.710	52.167	.543	-7.910	-7.877	-.033
11:58:13.1	49	55.540	55.008	.532	-8.229	-7.932	-.297
11:58:17.0	50	58.460	57.955	.505	-8.372	-7.937	-.435
11:58:20.9	51	61.380	60.911	.469	-8.168	-7.880	-.288
11:58:24.9	52	64.280	63.797	.483	-8.443	-7.901	-.542
11:58:28.8	53	67.200	66.655	.545	-7.828	-7.966	.138
11:58:32.7	54	70.090	69.611	.479	-8.251	-7.998	-.253
11:58:36.6	55	72.960	72.509	.451	-8.179	-8.040	-.139
11:58:40.6	56	75.830	75.382	.448	-7.982	-8.107	.125
11:58:44.5	57	78.730	78.144	.586	-8.234	-8.164	-.070
11:58:48.4	58	81.630	81.055	.575	-8.514	-8.218	-.296
11:58:52.3	59	84.490	84.042	.448	-8.701	-8.312	-.389
11:58:56.3	60	87.390	86.973	.417	-8.278	-8.418	.140
11:59: 4.1	62	93.280	92.728	.552	-8.833	-8.785	-.048
11:59: 8.0	63	96.220	95.705	.515	-9.240	-9.011	-.229

DAZ MEAN: -.092	DAZ S.D.:	.223	N= 43	SUM= -3.971	SUM OF SQUARES=	2.462
TOA MEAN: .393	TOA S.D.:	.137	N= 43	SUM= 16.912	SUM OF SQUARES=	7.445

AD-A058 936 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 1/4
EXPERIMENTAL BCAS PERFORMANCE RESULTS.(U)
JUL 78 J VILCANS, E QUISH, J G RAUDSEPS
UNCLASSIFIED TSC-FAA-78-9 FAA-RD-78-53 NL

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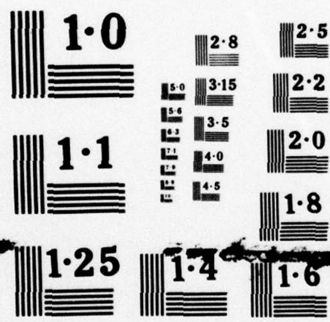

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0010
TARGET CODE: 0777 RUN 7 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12: 7:11.2	23	89.440	89.055	.385	-12.947	-12.482	-.465
12: 7:15.2	24	87.920	87.546	.374	-12.876	-12.400	-.476
12: 7:19.1	25	86.390	86.026	.364	-12.393	-12.336	-.057
12: 7:23.0	26	84.790	84.479	.311	-12.305	-12.301	-.004
12: 7:30.9	28	81.740	81.266	.474	-12.250	-12.194	-.056
12: 7:34.8	29	80.160	79.724	.436	-11.574	-12.115	.541
12: 7:38.8	30	78.590	78.121	.469	-11.997	-11.974	-.023
12: 7:46.6	32	75.450	75.163	.287	-11.464	-11.554	.090
12: 7:50.5	33	73.950	73.636	.314	-11.635	-11.309	-.326
12: 7:58.4	35	70.900	70.524	.376	-11.541	-11.080	-.461
12: 8: 2.3	36	69.390	68.978	.412	-11.618	-10.992	-.626
12: 8:18.0	40	63.430	63.141	.289	-10.443	-10.709	.266
12: 8:22.0	41	61.960	61.626	.334	-10.382	-10.624	.242
12: 8:25.9	42	60.430	60.104	.326	-10.629	-10.546	-.083
12: 8:29.8	43	59.000	58.613	.387	-10.816	-10.476	-.340
12: 8:33.7	44	57.500	57.082	.418	-10.096	-10.458	.362
12: 8:37.7	45	55.990	55.560	.430	-11.036	-10.451	-.585
12: 8:41.6	46	54.520	54.125	.395	-10.849	-10.445	-.404
12: 8:45.5	47	53.080	52.701	.379	-10.459	-10.424	-.035
12: 8:49.5	48	51.600	51.273	.327	-10.541	-10.424	-.117
12: 8:53.4	49	50.120	49.825	.295	-10.514	-10.401	-.113
12: 8:57.3	50	48.610	48.274	.336	-10.580	-10.370	-.210
12: 9: 1.2	51	47.150	46.760	.390	-10.206	-10.316	.110
12: 9: 9.1	53	44.190	43.729	.461	-9.981	-10.167	.186
12: 9:13.0	54	42.680	42.286	.394	-9.904	-10.089	.185
12: 9:17.0	55	41.210	40.847	.363	-10.305	-10.000	-.305
12: 9:20.9	56	39.730	39.407	.323	-9.778	-9.964	.186
12: 9:24.8	57	38.280	37.967	.313	-9.965	-9.936	-.029
12: 9:28.8	58	36.920	36.535	.385	-9.899	-9.985	.086
12: 9:32.7	59	35.570	35.127	.443	-10.206	-10.026	-.180
12: 9:36.6	60	34.230	33.796	.434	-9.157	-10.156	.999
12: 9:40.5	61	32.960	32.593	.367	-10.854	-10.312	-.542
12: 9:44.5	62	31.700	31.330	.370	-10.849	-10.413	-.436
12: 9:48.4	63	30.450			-10.635		
12: 9:52.3	64	29.220	28.905	.315	-10.728	-10.556	-.172
12: 9:56.2	65	28.020	27.644	.376	-10.481	-10.573	.092
12:10: .2	66	26.780	26.351	.429	-10.629	-10.531	-.098
12:10: 4.1	67	25.560	25.143	.417	-11.080	-10.483	-.597
12:10: 8.0	68	24.370	24.014	.356	-10.360	-10.442	.082
12:10:11.9	69	23.200	22.884	.316	-10.492	-10.355	-.137
12:10:15.9	70	22.060	21.735	.325	-10.404	-10.240	-.164
12:10:19.8	71	20.950	20.659	.291	-10.102	-10.145	.043
12:10:23.7	72	19.870	19.534	.336	-10.031	-10.049	.018
12:10:27.7	73	18.860	18.464	.396	-9.789	-9.954	.165
12:10:31.6	74	17.800	17.463	.337	-10.047	-9.857	-.190
12:10:35.5	75	16.910	16.493	.417	-9.987	-9.768	-.219

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0011

TARGET CODE: 0777 RUN 7 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:10:39.5	76	15.910	15.556	.354	-10.118	-9.642	-.476
12:10:43.4	77	14.990	14.722	.268	-9.360	-9.544	.184
12:10:47.3	78	14.160	13.889	.271	-9.558	-9.443	-.115
12:10:51.2	79	13.320	13.065	.255	-9.355	-9.338	-.017
12:10:55.2	80	12.560	12.343	.217	-9.371	-9.258	-.113
12:10:59.1	81	11.950	11.642	.308	-8.421	-9.206	.785
12:11: 3.0	82	11.350	11.043	.307	-10.129	-9.191	-.938
12:11:10.9	84	10.430	10.255	.175	-9.586	-9.393	-.193
12:11:18.7	86	9.670	9.469	.201	-9.882	-9.473	-.409
12:11:26.6	88	8.970	8.722	.248	-9.712	-9.584	-.128
12:11:30.5	89	8.660	8.404	.256	-9.987	-9.638	-.349
12:11:34.5	90	8.300	8.104	.196	-9.904	-9.678	-.226
12:11:38.4	91	7.970	7.796	.174	-10.036	-9.675	-.361
12:11:42.3	92	7.720	7.485	.235	-9.547	-9.661	.114
12:11:50.2	94	7.150	6.966	.184	-9.536	-9.683	.147
12:11:54.1	95	6.960	6.698	.262	-9.459	-9.651	.192
12:11:58.0	96	6.670	6.456	.214	-9.750	-9.636	-.114
12:12: 2.0	97	6.410	6.238	.172	-8.333	-9.597	1.264
12:12: 5.9	98	6.210	6.031	.179	-10.096	-9.574	-.522
12:12: 9.8	99	6.050	5.813	.237	-9.492	-9.537	.045
12:12:17.7	101	5.620	5.452	.168	-9.646	-9.482	-.164
12:12:21.6	102	5.450	5.259	.191	-9.695	-9.426	-.269
12:12:25.5	103	5.250	5.092	.158	-9.196	-9.389	.193
12:12:37.3	106	4.780	4.627	.153	-9.377	-9.252	-.125
12:12:41.2	107	4.720	4.501	.219	-9.404	-9.236	-.168
12:12:53.0	110	4.360	4.173	.187	-8.069	-9.220	1.151
12:12:56.9	111	4.220	4.080	.140	-9.344	-9.215	-.129
12:13: .9	112	4.170	3.999	.171	-9.168	-9.223	.055
12:13: 4.8	113	4.080	3.920	.160	-9.608	-9.228	-.380
12:13:12.6	115	3.930	3.768	.162	-9.163	-9.238	.075

DAZ MEAN: -.064 DAZ S.D.: .374 N= 75 SUM= -4.788 SUM OF SQUARES= 10.661

TOA MEAN: .308 TOA S.D.: .093 N= 75 SUM= 23.094 SUM OF SQUARES= 7.749

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0012

TARGET CODE: 0777 RUN 8 LCAS 045 11/9/76 ASR-6

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:16:56.6	3	4.930	4.716	.214	-9.794	-10.040	.246
12:17: .5	4	5.120	4.977	.143	-10.052	-10.141	.089
12:17: 4.4	5	5.340	5.184	.156	-10.228	-10.139	-.089
12:17: 8.3	6	5.530	5.361	.169	-10.541	-10.089	-.452
12:17:16.2	8	5.890	5.749	.141	-10.168	-9.903	-.265
12:17:20.1	9	6.160	5.975	.185	-8.893	-9.806	.913
12:17:24.1	10	6.430	6.217	.213	-9.959	-9.700	-.259
12:17:31.9	12	7.030	6.771	.259	-9.256	-9.462	.206
12:17:35.8	13	7.420	7.183	.237	-9.267	-9.439	.172
12:17:39.8	14	7.970	7.727	.243	-9.443	-9.488	.045
12:17:47.6	16	9.220	9.012	.208	-9.822	-9.635	-.187
12:17:55.5	18	10.760	10.466	.294	-9.827	-9.617	-.210
12:17:59.4	19	11.680	11.356	.324	-9.404	-9.645	.241
12:18: 7.3	21	13.870	13.574	.296	-10.003	-9.680	-.323
12:18:15.1	23	16.740	16.317	.423	-9.597	-9.782	.185
12:18:23.0	25	20.100	19.818	.282	-10.047	-9.881	-.166
12:18:30.8	27	24.070	23.631	.439	-10.129	-9.936	-.193
12:18:34.8	28	26.190	25.803	.387	-9.833	-10.012	.179
12:18:38.7	29	28.410	28.052	.358	-10.360	-10.019	-.341
12:18:42.6	30	30.750	30.367	.383	-10.096	-10.058	-.038
12:18:46.6	31	33.120	32.735	.385	-9.937	-10.086	.149
12:18:50.4	32	35.600	35.085	.515	-9.525	-10.102	.577
12:18:54.4	33	38.130	37.723	.407	-9.849	-10.124	.275
12:19: 2.2	35	43.300	42.806	.494	-9.871	-10.174	.303
12:19:10.1	37	48.640	48.250	.390	-10.519	-10.245	-.274
12:19:21.9	40	57.010	56.568	.442	-9.871	-10.445	.574
12:19:25.8	41	59.860	59.489	.371	-10.706	-10.556	-.150
12:19:29.7	42	62.780	62.374	.406	-10.344	-10.681	.337
12:19:33.6	43	65.640	65.125	.515	-11.497	-10.796	-.701
12:19:41.5	45	71.410	70.975	.435	-12.057	-11.006	-1.051
12:19:49.4	47	77.260	76.749	.511	-11.448	-11.259	-.189
12:19:57.3	49	83.030	82.620	.410	-11.492	-11.644	.152
12:20: 9.1	52	91.730	91.241	.489	-12.634	-12.226	-.408
12:20:13.0	53	94.610	94.144	.466	-11.816	-12.380	.564
12:20:17.0	54	97.490	97.163	.327	-12.250	-12.532	.282

DAZ MEAN: .006 DAZ S.D.: .387 N= 35 SUM= .193 SUM OF SQUARES= 5.098

TOA MEAN: .340 TOA S.D.: .116 N= 35 SUM= 11.917 SUM OF SQUARES= 4.519

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0004
TARGET CODE: 0777 RUN 9 LCAS 045 11/9/76 ASR-4 -3 OUTBOUND

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:33:15.0	94	2.760	2.613	.147	3.186	2.658	.528
12:33:22.8	96	2.610	2.382	.228	3.455	2.778	.677
12:33:26.8	97	2.410	2.280	.130	3.433	2.873	.560
12:33:30.7	98	2.410	2.188	.222	3.829	2.960	.869
12:33:34.6	99	2.220	2.093	.127	3.439	3.031	.408
12:33:38.5	100	2.240	2.032	.208	4.175	3.124	1.051
12:33:46.4	102	2.070	1.896	.174	3.878	3.258	.620
12:33:46.4	102	2.610			3.834		
12:33:50.2	103	2.000	1.857	.143	4.037	3.306	.731
12:34: 5.9	107	1.710	1.553	.157	3.768	3.184	.584
12:34: 9.9	108	1.680	1.475	.205	3.796	3.148	.648
12:34:13.8	109	1.560	1.428	.132	3.593	3.079	.514
12:34:21.6	111	1.560	1.308	.252	4.065	2.911	1.154
12:34:29.5	113	1.370	1.222	.148	3.192	2.854	.338

DAZ MEAN: .214 DAZ S.D.: .492 N= 59 SUM= 12.599 SUM OF SQUARES= 16.720
TOA MEAN: .274 TOA S.D.: .088 N= 59 SUM= 16.139 SUM OF SQUARES= 4.866

FORMAT SCAN ERROR AT 76412

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ILLEGAL CHARACTER: FIELD TERMINATED.

TBA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0003

TARGET CODE: 0777 RUN 9 LCAS 045 11/9/76 ASR-4 -3 OUTBOUND

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:28:28.0	21	98.690	98.504	.186	1.159	1.293	-.134
12:28:43.7	25	91.880	91.590	.290	1.483	1.675	-.192
12:28:47.6	26	90.070	89.807	.263	1.307	1.563	-.256
12:28:51.6	27	88.360	88.067	.293	1.165	1.476	-.311
12:28:55.5	28	86.590	86.324	.266	1.236	1.491	-.255
12:29: 3.4	30	83.150	82.868	.282	2.181	1.877	.304
12:29: 7.3	31	81.340	81.081	.259	1.802	2.002	-.200
12:29:11.2	32	79.680	79.342	.338	2.604	2.147	.457
12:29:15.2	33	78.090	77.564	.526	3.549	2.226	1.323
12:29:19.1	34	76.350	75.936	.414	2.510	2.261	.249
12:29:23.0	35	74.600	74.309	.291	2.450	2.308	.142
12:29:26.9	36	72.890	72.682	.208	2.571	2.358	.213
12:29:30.9	37	71.160	70.955	.205	2.598	2.430	.168
12:29:34.8	38	69.450	69.143	.307	2.565	2.490	.075
12:29:42.7	40	65.920	65.514	.406	2.324	2.588	-.264
12:29:50.5	42	62.400	62.111	.289	2.241	2.503	-.262
12:29:54.4	43	60.660	60.477	.183	2.016	2.445	-.429
12:30: 2.3	45	57.450	57.099	.351	2.549	2.311	.238
12:30: 6.2	46	55.770	55.445	.325	.692	2.244	-1.552
12:30:14.1	48	52.620	52.224	.396	1.637	2.094	-.457
12:30:18.0	49	51.050	50.716	.334	1.950	2.090	-.140
12:30:21.9	50	49.400	49.179	.221	1.961	2.129	-.168
12:30:25.9	51	47.730	47.531	.199	1.780	2.157	-.377
12:30:29.8	52	46.080	45.790	.290	2.164	2.184	-.020
12:30:33.7	53	44.370	44.044	.326	2.065	2.236	-.171
12:30:37.7	54	42.610	42.265	.345	2.324	2.335	-.011
12:30:41.6	55	40.920	40.516	.404	2.516	2.442	.074
12:30:49.4	57	37.510	37.284	.226	2.648	2.682	-.034
12:30:53.4	58	35.940	35.630	.310	2.812	2.805	.007
12:31:13.0	63	28.220	27.790	.430	3.351	2.818	.533
12:31:17.0	64	26.610	26.308	.302	2.620	2.611	.009
12:31:20.9	65	25.080	24.779	.301	3.087	2.450	.637
12:31:24.8	66	23.560	23.216	.344	3.307	2.303	1.004
12:31:36.6	69	19.200	18.780	.420	2.648	2.244	.404
12:31:40.6	70	17.810	17.463	.347	2.428	2.324	.104
12:31:48.5	72	15.180	14.943	.237	2.549	2.532	.017
12:32: .3	75	11.790	11.388	.402	2.670	2.699	-.029
12:32: 4.2	76	10.720	10.407	.313	3.203	2.724	.479
12:32:23.9	81	6.820	6.540	.280	3.312	2.830	.482
12:32:27.8	82	6.320	6.002	.318	3.433	2.835	.598
12:32:39.6	85	5.050	4.748	.302	3.939	2.778	1.161
12:32:47.5	87	4.300	4.082	.218	2.620	2.689	-.069
12:32:51.4	88	4.040	3.794	.246	3.285	2.663	.622
12:32:55.4	89	3.870	3.547	.323	2.741	2.657	.084
12:33: 3.2	91	3.300	3.127	.173	2.741	2.656	.085
12:33: 7.1	92	3.120	2.943	.177	2.433	2.654	-.221

TBA/DAZ ERROR ANALYSIS PROGRAM — DATE 24 JAN 1977 — PAGE 0002

TARGET CODE: 0777 — RUN 10 LCAS 045 11/9/76 ASR-4 INBOUND OVER FIRE TOWER

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:39:20.5	2	10.220	9.756	.464	3.669	3.298	.371
12:39:24.5	3	11.710	11.259	.451	3.082	3.231	-.149
12:39:28.4	4	13.340	12.998	.342	2.642	3.181	-.539
12:39:32.3	5	15.290	14.970	.320	2.922	3.084	-.162
12:39:40.2	7	19.740	19.212	.528	3.642	2.968	.674
12:39:44.1	8	22.040	21.570	.470	3.510	2.897	.613
12:39:48.1	9	24.500	24.170	.330	3.686	2.853	.833
12:39:52.1	10	27.080	26.711	.369	3.428	2.815	.613
12:39:59.9	12	32.380	31.910	.470	3.516	2.866	.650
12:40: 7.8	14	37.890	37.583	.307	3.252	3.042	.210
12:40:15.7	16	43.410	43.040	.370	3.658	3.103	.555
12:40:19.6	17	46.250	45.881	.369	3.115	3.117	-.002
12:40:27.4	19	51.940	51.504	.436	2.994	3.206	-.212
12:40:35.3	21	57.710	57.377	.333	2.714	3.199	-.485
12:40:39.3	22	60.690	60.341	.349	2.840	3.090	-.250
12:40:43.2	23	63.550	63.122	.428	2.637	2.915	-.278
12:40:51.0	25	69.280	68.912	.368	2.175	2.526	-.351
12:40:54.9	26	72.100	71.825	.275	2.296	2.342	-.046
12:40:58.8	27	75.050	74.574	.476	2.620	2.153	.467
12:41: 2.8	28	77.830	77.390	.440	1.708	2.038	-.330
12:41: 6.7	29	80.620	80.237	.383	1.730	1.988	-.258
12:41:14.6	31	86.170	85.838	.332	2.021	1.935	.086
12:41:26.4	34	94.200	93.932	.268	.330	1.260	-.930
12:41:30.3	35	96.960	96.660	.300	-.077	.883	-.960

DAZ MEAN: .005 DAZ S.D.: .506 N= 24 SUM= .120 SUM OF SQUARES= 5.884

TOA MEAN: .382 TOA S.D.: .071 N= 24 SUM= 9.178 SUM OF SQUARES= 3.627

.STOP. 00000000

TOA/DAZ ERROR ANALYSIS PROGRAM
TARGET CODE: 0777 RUN 11 LCAS 045 11/9/76 ASR-4 DATE 24 JAN 1977 PAGE 0005

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
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12:49:33.8	21	93.310			4.417		
12:49:37.7	22	91.620	91.168	.452	4.625	4.798	-.173
12:49:41.6	23	89.900	89.454	.446	5.059	5.144	-.085
12:49:45.6	24	88.210	87.760	.450	5.570	5.493	.077
12:49:49.5	25	86.430	86.118	.312	5.839	5.708	.131
12:49:53.4	26	84.710	84.400	.310	5.394	5.797	-.403
12:49:57.3	27	82.970	82.644	.326	5.806	5.816	-.010
12:50: 1.3	28	81.240	80.807	.433	5.317	5.702	-.385
12:50: 5.2	29	79.450	78.966	.484	5.334	5.604	-.270
12:50: 9.1	30	77.620	77.163	.457	5.186	5.546	-.360
12:50:13.1	31	75.830	75.381	.449	5.098	5.531	-.433
12:50:17.0	32	74.040	73.686	.354	5.444	5.528	-.084
12:50:20.9	33	72.300	71.979	.321	5.070	5.503	-.433
12:50:24.9	34	70.550	70.175	.375	5.147	5.462	-.315
12:50:28.8	35	68.870	68.462	.408	4.993	5.408	-.415
12:50:32.7	36	67.150	66.706	.444	5.317	5.325	-.008
12:50:36.7	37	65.500	64.963	.537	5.125	5.202	-.077
12:50:40.6	38	63.800	63.348	.452	4.823	5.091	-.268
12:50:44.5	39	62.080	61.772	.308	4.905	4.994	-.089
12:50:48.5	40	60.490	60.098	.392	4.691	4.935	-.244
12:50:52.4	41	58.810	58.430	.380	4.845	4.922	-.077
12:50:56.3	42	57.130	56.774	.356	4.384	4.922	-.538
12:51: .3	43	55.450	54.953	.497	4.510	4.908	-.398
12:51: 4.2	44	53.770			5.065		
12:51: 8.1	45	52.030	51.606	.424	5.219	5.056	.163
12:51:12.1	46	50.280	49.910	.370	4.774	5.159	-.385
12:51:16.0	47	48.540	48.221	.319	5.186	5.275	-.089
12:51:19.9	48	46.890	46.509	.381	5.663	5.410	.253
12:51:23.9	49	45.210	44.774	.436	5.416	5.553	-.137
12:51:27.8	50	43.540	43.087	.453	5.416	5.679	-.263
12:51:31.7	51	41.860	41.453	.407	5.416	5.795	-.379
12:51:35.6	52	40.310	39.902	.408	5.284	5.854	-.570
12:51:39.6	53	38.690	38.330	.360	5.609	5.902	-.293
12:51:43.5	54	37.100	36.717	.383	5.751	5.914	-.163
12:51:47.4	55	35.450	35.079	.371	5.609	5.926	-.317
12:51:51.4	56	33.830	33.399	.431	5.620	5.929	-.309
12:51:55.3	57	32.230	31.774	.456	5.762	5.939	-.177
12:51:59.2	58	30.640	30.188	.452	5.773	5.940	-.167
12:52: 3.2	59	29.100	28.652	.448	5.916	5.937	-.021
12:52: 7.1	60	27.550	27.221	.329	5.576	5.885	-.309
12:52:11.0	61	26.060	25.794	.266	5.806	5.832	-.026
12:52:15.0	62	24.680	24.326	.354	5.806	5.803	.003
12:52:18.9	63	23.290	22.886	.404	5.669	5.777	-.108
12:52:22.8	64	21.910	21.502	.408	5.883	5.767	.116
12:52:26.7	65	20.570	20.136	.434	6.070	5.739	.331
12:52:30.7	66	19.250	18.828	.422	5.691	5.724	-.033

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0006
TARGET CODE: 0777 RUN 11 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	EAIR TOA	TOA DIFF	BCAS DAZ	EAIR DAZ	DAZ DIFF
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12:52:34.6	67	17.950	17.567	.383	5.510	5.728	-.218
12:52:38.5	68	16.650	16.371	.279	5.301	5.709	-.408
12:52:42.4	69	15.510	15.181	.329	5.576	5.712	-.136
12:52:46.4	70	14.430	14.014	.416	5.735	5.719	.016
12:52:50.3	71	13.400	13.029	.371	5.768	5.711	.057
12:52:54.2	72	12.480	12.158	.322	5.532	5.716	-.184
12:52:58.2	73	11.660	11.315	.345	5.735	5.721	.014
12:53: 2.1	74	10.810	10.533	.277	5.636	5.715	-.079
12:53: 6.0	75	10.070	9.798	.272	5.537	5.705	-.168
12:53: 9.9	76	9.460	9.148	.312	5.471	5.758	-.287
12:53:13.9	77	8.840	8.544	.296	5.466	5.817	-.351
12:53:17.8	78	8.290	8.000	.290	5.674	5.865	-.191
12:53:21.7	79	7.830	7.532	.298	5.488	5.903	-.415
12:53:25.6	80	7.370	7.080	.290	5.856	5.953	-.097
12:53:29.6	81	6.930	6.675	.255	5.361	5.991	-.630
12:53:33.5	82	6.480	6.238	.242	5.883	5.986	-.103
12:53:37.4	83	6.140	5.880	.260	6.048	5.960	.088
12:53:41.4	84	5.700	5.480	.220	5.872	5.945	-.073
12:53:45.3	85	5.420	5.193	.227	5.933	5.929	.004
12:53:49.2	86	5.120	4.902	.218	5.669	5.914	-.245
12:53:53.1	87	4.860	4.659	.201	5.883	5.913	-.030
12:53:57.1	88	4.670	4.422	.248	6.075	5.896	.179
12:54: 1.0	89	4.400	4.202	.198	5.856	5.892	-.036
12:54: 4.9	90	4.240	4.004	.236	5.691	5.866	-.175
12:54:12.8	92	3.860	3.657	.203	5.806	5.848	-.042
12:54:16.7	93	3.700	3.522	.178	5.999	5.876	.123
12:54:24.6	95	3.480	3.319	.161	5.883	5.947	-.064
12:54:28.5	96	3.430	3.215	.215	5.977	5.974	.003
12:54:32.5	97	3.260	3.093	.167	5.691	5.991	-.300
12:54:36.4	98	3.210	3.011	.199	5.867	6.020	-.153
12:54:40.3	99	3.090	2.906	.184	5.680	6.028	-.348
12:54:44.3	100	3.040	2.835	.205	6.070	6.049	.021
12:54:48.2	101	2.840	2.763	.077	5.883	6.068	-.185
12:54:52.1	102	2.870	2.693	.177	5.938	6.087	-.149
12:55: .0	104	2.720	2.533	.187	6.312	6.091	.221
12:55: 3.9	105	2.610	2.456	.154	6.059	6.086	-.027
12:55:11.8	107	2.490	2.313	.177	5.773	6.058	-.285
12:55:15.7	108	2.410	2.245	.165	5.867	6.067	-.200
12:55:19.6	109	2.300	2.192	.108	6.042	6.064	-.022

DAZ MEAN:	-.152	DAZ S.D.:	.193	N= 83	SUM=	-12.612 SUM OF SQUARES=	4.987
TOA MEAN:	.325	TOA S.D.:	.105	N= 83	SUM=	27.001 SUM OF SQUARES=	9.683

TBA/DAZ ERROR ANALYSIS PROGRAM
TARGET CODE: 0777 RUN 2,LCAS 045,11/9/76,ASR4 DATE = NO DATE = PAGE 0002

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
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11:12: 4.8	5	18.510			-1.791		
11:12:12.7	7	23.740			-2.241		
11:12:16.6	8	26.530	27.377	-.847	-2.450	-2.021	-.429
11:12:24.5	10	32.260	32.918	-.658	-1.851	-2.021	.170
11:12:28.4	11	35.110			-2.076		
11:12:32.3	12	38.170			-1.741		
11:12:36.2	13	41.130			-2.247		
11:12:40.2	14	44.120	44.504	-.384	-2.098	-2.109	.011
11:12:48.0	16	50.250	51.245	-.995	-2.263	-2.637	.374
11:12:51.9	17	53.320			-2.192		
11:12:55.8	18	56.420	57.230	-.810	-2.390	-2.373	-.017
11:12:59.7	19	59.520			-1.588		
11:13: 3.7	20	62.660	63.347	-.687	-2.653	-2.988	.335
11:13: 7.6	21	65.760			-2.131		
11:13:11.5	22	68.920			-3.071		
11:13:15.4	23	72.010	72.502	-.492	-2.889	-2.725	-.164
11:13:19.4	24	75.180			-2.494		
11:13:23.3	25	78.190	78.687	-.497	-3.005	-2.988	-.017
11:13:27.2	26	81.340	81.797	-.457	-2.653	-3.164	.511
11:13:31.2	27	84.410	84.906	-.496	-3.505	-3.164	-.341
11:13:39.0	29	90.620	91.186	-.566	-3.895	-3.691	-.204
11:13:42.9	30	93.740	94.344	-.604	-3.933	-3.955	.022
11:13:46.9	31	96.740	94.311	2.429	-3.867	-3.867	.000

DAZ MEAN: .019 DAZ S.D.: .275 N= 13 SUM= .251 SUM OF SQUARES= .912
TBA MEAN: -.390 TBA S.D.: .865 N= 13 SUM= -5.064 SUM OF SQUARES= 10.945

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0003

TARGET CODE: 0777 RUN 3,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:22:49.0	33	80.050			-6.163		
11:22:52.9	34	78.590			-6.438		
11:22:56.8	35	77.090	77.478	-.388	-6.833	-6.416	-.417
11:23: .7	36	75.550	75.925	-.375	-5.784	-6.240	.456
11:23: 4.6	37	74.040			-4.592		
11:23: 8.6	38	72.500	72.800	-.300	-5.449	-5.713	.264
11:23:16.4	40	69.400			-4.999		
11:23:20.3	41	67.860	68.107	-.247	-4.949	-5.186	.237
11:23:24.2	42	66.280	66.540	-.260	-4.949	-4.834	-.115
11:23:28.2	43	64.650	64.943	-.293	-4.757	-4.219	-.538
11:23:32.1	44	63.070	63.497	-.427	-4.878	-4.746	-.132
11:23:39.9	46	60.030	60.414	-.384	-3.367	-4.307	.940
11:23:43.8	47	58.450	58.870	-.420	-4.708	-4.043	-.665
11:23:47.8	48	56.940	57.404	-.464	-4.735	-4.307	-.428
11:23:51.7	49	55.490			-3.774		
11:23:55.6	50	54.000	54.367	-.367	-4.532	-4.043	-.489
11:23:59.5	51	52.540			-4.631		
11:24: 3.4	52	51.100	51.431	-.331	-4.515	-4.307	-.208
11:24: 7.3	53	49.600	49.948	-.348	-4.213	-4.307	.094
11:24:11.3	54	48.140	48.524	-.384	-4.631	-4.570	-.061
11:24:15.2	55	46.660	47.133	-.473	-4.872	-4.922	.050
11:24:19.1	56	45.230			-5.054		
11:24:23.0	57	43.800	44.175	-.375	-4.466	-4.746	.280
11:24:26.9	58	42.430			-4.158		
11:24:30.9	59	41.040			-3.983		
11:24:38.7	61	38.240	38.950	-.710	-4.246	-4.043	-.203
11:24:42.6	62	36.900	37.567	-.667	-4.202	-4.219	.017
11:24:46.6	63	35.520	35.950	-.430	-4.252	-3.428	-.824
11:24:50.5	64	34.220			-3.774		
11:24:54.4	65	32.880	29.255	3.625	-3.439	-3.779	.340
11:24:58.3	66	31.530			-5.048		
11:25: 2.2	67	30.170	30.308	-.138	-4.125	-3.252	-.873
11:25:14.0	70	26.220	27.028	-.808	-4.279	-3.604	-.675
11:25:17.9	71	24.970	25.769	-.799	-3.461	-3.779	.318
11:25:21.9	72	23.680	24.442	-.762	-3.686	-3.691	.005
11:25:25.8	73	22.430	23.236	-.806	-3.950	-3.867	-.083
11:25:29.7	74	21.210	22.142	-.932	-4.202	-4.219	.017
11:25:33.6	75	20.020	20.932	-.912	-4.136	-4.219	.083
11:25:37.6	76	18.950	19.796	-.846	-4.504	-4.307	-.197
11:25:41.5	77	17.910	18.355	-.445	-4.598	-3.691	-.907
11:25:45.4	78	16.930			-5.707		
11:25:49.4	79	15.990	9.929	6.061	-4.356	-4.219	-.137
11:25:53.3	80	14.990	15.953	-.963	-4.356	-4.131	-.225
11:25:57.2	81	14.010	14.997	-.987	-3.724	-4.219	.495
11:26: 1.2	82	13.090	6.918	6.172	-4.175	-3.955	-.220
11:26: 5.1	83	12.200			-3.801		

TBA/DAZ ERROR ANALYSIS PROGRAM
TARGET CODE: 0777 RUN 3,LCAS 045,11/9/76,ASR4 DATE . NO DATE . PAGE 0004

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
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11:26: 9.0	84	11.400			-3.752		
11:26:12.9	85	10.540			-4.329		
11:26:36.5	91	7.020	7.804	-.784	-3.983	-4.043	.060
11:26:40.4	92	6.590	7.113	-.523	-4.120	-3.691	-.429
11:26:48.3	94	5.710	5.992	-.282	-3.400	-3.164	-.236
11:27: .1	97	4.700	5.088	-.388	-3.389	-3.428	.039
11:27: 4.0	98	4.430	5.108	-.678	-3.444	-3.779	.335
11:27:15.8	101	3.770	4.078	-.308	-3.593	-3.428	-.165
11:27:19.7	102	3.640	3.870	-.230	-4.021	-3.164	-.857
11:27:23.6	103	3.520	3.779	-.259	-3.642	-3.428	-.214
11:27:27.6	104	3.340	3.599	-.259	-4.114	-3.428	-.686
11:27:31.5	105	3.280	3.502	-.222	-3.631	-3.604	-.027
11:27:35.4	106	3.130	3.312	-.182	-3.323	-3.516	.193
11:27:39.3	107	3.020	3.169	-.149	-3.593	-3.516	-.077
11:27:43.3	108	2.870	.671	2.199	-3.686	-3.340	-.346
11:27:47.2	109	2.750	2.821	-.071	-4.197	-3.252	-.945
11:27:51.1	110	2.620	2.766	-.146	-4.005	-3.428	-.577
11:27:59.0	112	2.430	2.568	-.138	-3.829	-3.604	-.225
11:28: 2.9	113	2.360	2.392	-.032	-4.252	-3.340	-.912
11:28: 6.8	114	2.180	2.231	-.051	-3.686	-3.076	-.610
11:28:10.8	115	2.100	2.152	-.052	-3.208	-3.076	-.132
11:28:14.7	116	2.010	.398	1.612	-3.609	-2.900	-.709
11:28:22.5	118	1.880	2.118	-.238	-3.571	-3.691	.120
11:28:26.5	119	1.750	1.951	-.201	-3.527	-3.340	-.187
11:28:34.3	121	1.710	1.726	-.016	-3.505	-2.900	-.605
11:28:38.2	122	1.640	1.599	.041	-3.378	-2.549	-.829
11:28:42.2	123	1.550	1.731	-.181	-3.395	-3.340	-.055
11:28:46.1	124	1.500	1.598	-.098	-3.274	-2.988	-.286
11:28:50.1	125	1.560	1.534	.026	-3.340	-2.900	-.440
11:28:54.0	126	1.420	1.530	-.110	-3.318	-3.076	-.242
11:28:57.9	127	1.410			-3.318		
11:29: 1.8	128	1.420	.480	.940	-3.922	-3.604	-.318

DAZ MEAN:	-.212	DAZ S.D.:	.398	N=	62 SUM=	-13.163	SUM OF SQUARES=	12.446
TBA MEAN:	-.016	TBA S.D.:	1.336	N=	62 SUM=	-.963	SUM OF SQUARES=	108.842

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0002
TARGET CODE: 0777 RUN 4,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:34: 4.2	11	4.070	4.307	-.237	-3.005	-3.164	.159
11:34: 8.1	12	4.500	5.108	-.608	-3.115	-3.779	.664
11:34:12.0	13	5.120	5.742	-.622	-3.554	-3.779	.225
11:34:15.9	14	5.840	6.595	-.755	-3.027	-3.955	.928
11:34:19.9	15	6.740	7.353	-.613	-3.505	-3.691	.186
11:34:31.6	18	10.650			-3.779		
11:34:35.6	19	12.430	13.203	-.773	-3.181	-3.340	.159
11:34:39.5	20	14.410			-3.719		
11:34:43.4	21	16.560	17.124	-.564	-3.911	-2.988	-.923
11:34:47.3	22	18.890	19.685	-.795	-3.917	-3.691	-.226
11:34:51.3	23	21.460	22.054	-.594	-4.208	-3.604	-.604
11:34:55.2	24	23.990	24.454	-.464	-4.180	-3.252	-.928
11:34:59.1	25	26.690	27.331	-.641	-4.257	-4.043	-.214
11:35: 7.0	27	32.240	32.691	-.451	-4.016	-3.867	-.149
11:35:10.9	28	35.080	35.581	-.501	-4.400	-4.219	-.181
11:35:14.8	29	37.970	38.366	-.396	-4.076	-4.043	-.033
11:35:18.8	30	40.890	41.179	-.289	-4.455	-3.779	-.676
11:35:30.5	33	49.750	49.918	-.168	-4.241	-3.428	-.813
11:35:34.5	34	52.730	52.989	-.259	-3.994	-4.043	.049
11:35:38.4	35	55.690	56.018	-.328	-4.224	-4.307	.083
11:35:42.3	36	58.800	56.669	2.131	-3.999	-3.955	-.044
11:35:46.2	37	61.780			-4.158		
11:35:50.2	38	64.910			-3.708		
11:35:54.1	39	67.950	68.820	-.870	-4.356	-3.867	-.489
11:35:58.0	40	71.050	68.949	2.101	-4.592	-4.043	-.549
11:36: 1.9	41	74.210			-4.263		
11:36: 5.8	42	77.260	78.100	-.840	-4.763	-4.658	-.105
11:36: 9.8	43	80.440			-4.279		
11:36:17.6	45	86.680			-5.301		
11:36:21.6	46	89.800	90.550	-.750	-5.982	-5.098	-.884
11:36:25.5	47	92.960	92.945	.015	-5.773	-5.713	-.060
11:36:29.4	48	96.030	93.651	2.379	-6.147	-5.537	-.610
11:36:33.3	49	99.120	100.087	-.967	-6.828	-6.416	-.412

DAZ MEAN: -.210 DAZ S.D.: .471 N= 26 SUM= -5.447 SUM OF SQUARES= 6.676
TBA MEAN: -.225 TBA S.D.: .926 N= 26 SUM= -5.859 SUM OF SQUARES= 22.758

TBA/DAZ ERROR ANALYSIS PROGRAM   DATE • NO DATE •   PAGE   0003
TARGET CODE: 0777   RUN 5,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:45:47.1	17	98.680	99.487	-.807	-9.223	-9.492	.269
11:45:51.1	18	97.150			-8.833		
11:45:55.0	19	95.650	96.331	-.681	-9.025	-9.053	.028
11:45:58.9	20	94.120			-9.772		
11:45:58.9	20	94.120			-7.004		
11:46: 2.8	21	92.600	90.093	2.507	-8.427	-8.174	-.253
11:46: 6.7	22	91.080	88.548	2.532	-8.075	-7.998	-.077
11:46:10.7	23	89.610			-7.592		
11:46:14.6	24	88.140	85.468	2.672	-7.712	-7.734	.022
11:46:18.5	25	86.610	83.934	2.676	-7.504	-7.646	.142
11:46:22.4	26	85.150	82.399	2.751	-7.564	-7.559	-.005
11:46:26.4	27	83.670	80.814	2.856	-7.147	-7.119	-.028
11:46:30.3	28	82.190	79.370	2.820	-7.504	-7.646	.142
11:46:34.2	29	80.790	78.556	2.234	-7.108	-7.295	.187
11:46:38.1	30	79.330			-7.432		
11:46:42.0	31	77.880	78.501	-.621	-7.943	-7.822	-.121
11:46:46.0	32	76.490	76.993	-.503	-8.229	-7.910	-.319
11:46:49.9	33	75.110	75.553	-.443	-8.229	-8.350	.121
11:46:53.8	34	73.700	74.075	-.375	-8.657	-8.525	-.132
11:46:57.7	35	72.280	72.568	-.288	-8.580	-8.525	-.055
11:47: 1.7	36	70.840	70.975	-.135	-8.339	-8.086	-.253
9:36:21.7	38	67.920			-8.828		
9:36:25.6	39	66.470			-8.959		
9:36:29.6	40	65.020			-8.416		
9:36:33.5	41	63.490			-8.734		
9:36:37.4	42	62.040			-7.646		
9:36:41.3	43	60.540			-7.476		
9:36:45.2	44	59.020			-7.586		
9:36:49.2	45	57.530			-7.224		
9:36:53.1	46	56.040			-8.383		
9:36:57.0	47	54.420			-7.575		
11:47:48.8	48	52.890	53.563	-.673	-7.471	-6.943	-.528
11:47:52.7	49	51.480			-6.498		
11:47:56.6	50	49.860	50.593	-.733	-6.465	-6.768	.303
11:48: 4.5	52	46.900			-7.449		
11:48: 8.4	53	45.390	45.660	-.270	-7.240	-7.119	-.121
11:48:12.3	54	43.950	44.144	-.194	-6.729	-6.855	.126
11:48:20.2	56	40.900	41.352	-.452	-7.191	-6.943	-.248
11:48:24.1	57	39.430	39.955	-.525	-7.218	-6.943	-.275
11:48:28.0	58	37.950	38.680	-.730	-7.608	-7.207	-.401
11:48:31.9	59	36.510	37.430	-.920	-7.059	-7.471	.412
11:48:35.8	60	35.010	35.870	-.860	-6.855	-7.031	.176
11:48:39.8	61	33.640	33.854	-.214	-7.086	-7.031	-.055
11:48:43.7	62	32.160	32.711	-.551	-7.405	-7.383	-.022
11:48:47.6	63	30.760	31.508	-.748	-7.163	-7.559	.396
11:48:51.5	64	29.450	30.128	-.678	-7.690	-7.383	-.307

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0004
TARGET CODE: 0777 RUN 5,LCAS C45,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:48:55.5	65	28.090	28.917	-.827	-7.460	-7.471	.011
11:48:59.4	66	26.680	27.623	-.943	-6.850	-7.383	.533
11:49: 7.2	68	24.080	20.653	3.427	-7.103	-7.031	-.072
11:49:11.2	69	22.830	23.288	-.458	-6.828	-7.119	.291
11:49:15.1	70	21.540	22.159	-.619	-6.531	-7.119	.588
11:49:19.0	71	20.340	16.433	3.907	-7.070	-6.504	-.566
11:49:23.0	72	19.140	19.181	-.041	-6.669	-5.977	-.692
11:49:30.8	74	16.930	17.178	-.248	-6.548	-6.064	-.484
11:49:34.7	75	15.880	16.323	-.443	-6.449	-6.328	-.121
11:49:38.7	76	14.880	10.472	4.408	-6.389	-6.416	.027
11:49:42.6	77	13.950	9.536	4.414	-6.921	-6.680	-.241
11:49:46.5	78	13.070	8.890	4.180	-6.636	-6.768	.132
11:49:50.4	79	12.270	12.598	-.328	-6.526	-6.328	-.198
11:49:54.3	80	11.520	7.224	4.296	-6.768	-6.504	-.264
11:49:58.3	81	10.980	11.134	-.154	-6.581	-6.152	-.429
11:50: 2.2	82	10.340	11.009	-.669	-6.400	-6.768	.368
11:50: 6.1	83	9.730	10.122	-.392	-6.416	-6.416	.000
11:50:10.1	84	9.200	9.789	-.589	-6.509	-6.680	.171
11:50:14.0	85	8.720	9.057	-.337	-6.482	-6.416	-.066
11:50:17.9	86	8.300			-6.570		
11:50:21.8	87	7.790	4.177	3.613	-6.389	-6.328	-.061
11:50:25.8	88	7.390	4.207	3.183	-6.295	-6.592	.297
11:50:29.7	89	6.960	3.980	2.980	-6.751	-6.592	-.159
11:50:33.6	90	6.590			-6.246		
11:50:41.5	92	5.920	3.036	2.884	-6.279	-6.240	-.039
11:50:45.4	93	5.690	5.964	-.274	-6.619	-6.504	-.115
11:50:49.3	94	5.430	5.701	-.271	-6.515	-6.416	-.099
11:50:53.3	95	5.220	5.527	-.307	-6.905	-6.504	-.401
11:50:57.2	96	5.030			-6.119		
11:51: 1.1	97	4.860	2.305	2.555	-6.185	-6.064	-.121
11:51: 5.1	98	4.640	4.441	.199	-6.454	-5.889	-.565
11:51: 9.0	99	4.430	4.380	.050	-6.509	-6.064	-.445
11:51:12.9	100	4.320			-5.922		
11:51:16.8	101	4.110			-6.400		
11:51:20.8	102	3.950			-6.636		
11:51:24.7	103	3.840	3.873	-.033	-6.872	-6.240	-.632
11:51:28.6	104	3.710	3.909	-.199	-6.691	-6.680	-.011
11:51:32.5	105	3.570	1.791	1.779	-6.196	-6.064	-.132
11:51:36.5	106	3.510	3.618	-.108	-6.147	-6.504	.357
11:51:40.4	107	3.400			-6.751		
11:51:44.3	108	3.310	3.563	-.253	-6.658	-6.768	.110
11:51:48.3	109	3.190	3.469	-.279	-6.740	-6.768	.028
11:51:52.2	110	3.120			-6.411		
11:51:56.1	111	3.040			-6.515		
11:52: .0	112	2.970			-7.663		
11:52: .1	112	2.940			-5.048		

TBA/DAZ ERROR ANALYSIS PROGRAM DATE - NO DATE - PAGE 0005
TARGET CODE: 0777 RUN 5,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:52: 4.0	113	2.870	3.127	-.257	-6.443	-6.768	.325
11:52: 7.9	114	2.780			-6.224		
11:52:11.8	115	2.690	1.608	1.082	-6.196	-6.416	.220
11:52:15.8	116	2.630			-6.290		
11:52:23.6	118	2.480	2.464	.016	-5.900	-6.064	.164
11:52:27.5	119	2.400	2.314	.086	-6.279	-5.889	-.390
11:52:31.5	120	2.390	2.266	.124	-6.575	-5.889	-.686

DAZ MEAN: -.061 DAZ S.D.: .293 N= 69 SUM= -4.243 SUM OF SQUARES= 6.091
TBA MEAN: .649 TBA S.D.: 1.676 N= 69 SUM= 44.801 SUM OF SQUARES= 220.209

TOA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0002
TARGET CODE: 0777 RUN 6 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	ARTS TOA	TOA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
11:55:59.6	15	2.680	.881	1.799	-5.339	-4.395	-.944
11:56: 3.5	16	2.850	2.551	.299	-5.037	-4.219	-.818
11:56: 7.4	17	3.020	2.729	.291	-5.125	-4.219	-.906
11:56:11.4	18	3.250	3.258	-.008	-5.268	-5.098	-.170
11:56:15.3	19	3.530			-5.674		
11:56:23.1	21	4.070	4.279	-.209	-5.400	-5.537	.137
11:56:27.1	22	4.400	4.297	.103	-5.922	-4.922	-1.000
11:56:31.0	23	4.870	4.963	-.093	-6.059	-5.361	-.698
11:56:34.9	24	5.320	5.623	-.303	-5.878	-5.625	-.253
11:56:38.9	25	5.980	6.231	-.251	-5.916	-5.889	-.027
11:56:42.8	26	6.670	7.086	-.416	-5.779	-6.152	.373
11:56:46.7	27	7.450	7.599	-.149	-6.152	-5.801	-.351
11:56:50.6	28	8.380	8.986	-.606	-6.125	-6.328	.203
11:56:54.5	29	9.440			-6.581		
11:56:58.5	30	10.610	10.740	-.130	-6.910	-6.064	-.846
11:57: 2.4	31	12.030	12.168	-.138	-6.762	-6.152	-.610
11:57: 6.3	32	13.610	14.277	-.667	-6.718	-6.855	.137
11:57:10.3	33	15.220	15.838	-.618	-6.817	-6.680	-.137
11:57:14.2	34	17.050	17.987	-.937	-7.020	-7.031	.011
11:57:22.1	36	21.290	22.097	-.807	-7.075	-7.031	-.044
11:57:26.0	37	23.580	23.805	-.225	-7.339	-7.031	-.308
11:57:29.9	38	25.920	26.405	-.485	-7.322	-7.383	.061
11:57:33.8	39	28.440	28.917	-.477	-7.180	-7.471	.291
11:57:37.8	40	30.930	31.383	-.453	-7.630	-7.207	-.423
11:57:45.6	42	36.190	37.027	-.837	-7.482	-7.910	.428
11:57:49.5	43	38.800			-8.113		
11:57:53.5	44	41.490	42.427	-.937	-8.152	-7.734	-.418
11:57:57.4	45	44.290			-8.069		
11:58: 1.3	46	47.060			-8.251		
11:58: 9.2	48	52.710	53.258	-.548	-7.910	-8.350	.440
11:58:13.1	49	55.540	56.005	-.465	-8.229	-7.822	-.407
11:58:17.0	50	58.460	59.013	-.553	-8.372	-8.086	-.286
11:58:20.9	51	61.380	61.877	-.497	-8.168	-7.734	-.434
11:58:24.9	52	64.280	64.996	-.716	-8.443	-8.350	-.093
11:58:28.8	53	67.200	67.792	-.592	-7.828	-7.471	-.357
11:58:32.7	54	70.090	70.188	-.098	-8.251	-7.910	-.341
11:58:36.6	55	72.960			-8.179		
11:58:40.6	56	75.830	76.234	-.404	-7.982	-7.910	-.072
11:58:44.5	57	78.730	79.334	-.604	-8.234	-8.262	.028
11:58:48.4	58	81.630	82.414	-.784	-8.514	-8.437	-.077
11:58:52.3	59	84.490	85.478	-.988	-8.701	-8.437	-.264
11:58:56.3	60	87.390	87.787	-.397	-8.278	-8.437	.159
11:59: 4.1	62	93.280			-8.833		
11:59: 8.0	63	96.220	96.331	-.111	-9.240	-9.053	-.187
11:59:12.0	64	99.150	99.507	-.357	-9.130	-9.492	.362

DAZ MEAN: -.206 DAZ S.D.: .391 N= 38 SUM= -7.841 SUM OF SQUARES= 7.266
TOA MEAN: -.352 TOA S.D.: .480 N= 38 SUM= -13.368 SUM OF SQUARES= 13.238

TBA/DAZ ERROR ANALYSIS PROGRAM DATE 24 JAN 1977 PAGE 0003

TARGET CODE: 0777 RUN 7 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TOA	ARTS TOA	TOA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
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12: 7:11.2	23	89.440	89.114	.326	-12.947	-12.305	-.642
12: 7:15.2	24	87.920	88.290	-.370	-12.876	-11.953	-.923
12: 7:19.1	25	86.390			-12.393		
12: 7:23.0	26	84.790	85.373	-.583	-12.305	-12.480	.175
12: 7:30.9	28	81.740			-12.250		
12: 7:34.8	29	80.160			-11.574		
12: 7:38.8	30	78.590	79.327	-.737	-11.997	-12.217	.220
12: 7:46.6	32	75.450	75.573	-.123	-11.464	-12.041	.577
12: 7:50.5	33	73.950	74.048	-.098	-11.635	-11.865	.230
12: 7:58.4	35	70.900	71.621	-.721	-11.541	-11.074	-.467
12: 8: 2.3	36	69.390	70.083	-.693	-11.618	-10.811	-.807
12: 8:18.0	40	63.430	64.020	-.590	-10.443	-10.195	-.248
12: 8:22.0	41	61.960	62.671	-.711	-10.382	-10.547	.165
12: 8:25.9	42	60.430	60.380	.050	-10.629	-10.195	-.434
12: 8:29.8	43	59.000			-10.816		
12: 8:33.7	44	57.500	57.311	.189	-10.096	-9.668	-.428
12: 8:37.7	45	55.990	56.193	-.203	-11.036	-10.547	-.489
12: 8:41.6	46	54.520	54.722	-.202	-10.849	-10.283	-.566
12: 8:45.5	47	53.080	53.357	-.277	-10.459	-10.547	.088
12: 8:49.5	48	51.600	51.623	-.023	-10.541	-9.756	-.785
12: 8:53.4	49	50.120	50.286	-.166	-10.514	-9.932	-.582
12: 8:57.3	50	48.610	48.925	-.315	-10.580	-10.020	-.560
12: 9: 1.2	51	47.150	47.495	-.345	-10.206	-9.932	-.274
12: 9: 9.1	53	44.190	44.239	-.049	-9.981	-10.283	.302
12: 9:13.0	54	42.680	42.937	-.257	-9.904	-10.371	.467
12: 9:17.0	55	41.210	41.410	-.200	-10.305	-10.020	-.285
12: 9:20.9	56	39.730	40.082	-.352	-9.778	-10.020	.242
12: 9:24.8	57	38.280	38.615	-.335	-9.965	-9.756	-.209
12: 9:28.8	58	36.920	37.361	-.441	-9.899	-9.844	-.055
12: 9:32.7	59	35.570	36.293	-.723	-10.206	-10.195	-.011
12: 9:36.6	60	34.230			-9.157		
12: 9:40.5	61	32.960	33.167	-.207	-10.854	-10.195	-.659
12: 9:44.5	62	31.700	32.465	-.765	-10.849	-10.898	.049
12: 9:48.4	63	30.450	31.085	-.635	-10.635	-10.635	.000
12: 9:52.3	64	29.220	30.342	-1.122	-10.728	-11.162	.434
12: 9:56.2	65	28.020	28.736	-.716	-10.481	-11.250	.769
12:10: .2	66	26.780	27.048	-.268	-10.629	-10.547	-.082
12:10: 4.1	67	25.560			-11.080		
12:10: 8.0	68	24.370	24.846	-.476	-10.360	-10.459	.099
12:10:11.9	69	23.200	24.148	-.948	-10.492	-10.811	.319
12:10:15.9	70	22.060	22.674	-.614	-10.404	-10.283	-.121
12:10:19.8	71	20.990	22.132	-1.182	-10.102	-10.723	.621
12:10:23.7	72	19.870			-10.031		
12:10:27.7	73	18.880	19.486	-.606	-9.789	-9.844	.055
12:10:31.6	74	17.800			-10.047		
12:10:35.5	75	16.910			-9.987		

TBA/DAZ ERROR ANALYSIS PROGRAM — DATE 24 JAN 1977 — PAGE 0004

TARGET CODE: 0777 — RUN 7 LCAS 045 11/9/76 ASR-4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:10:39.5	76	15.910	16.954	-1.044	-10.118	-10.195	.077
12:10:43.4	77	14.990	15.881	-.891	-9.360	-9.668	.308
12:10:47.3	78	14.160			-9.558		
12:10:51.2	79	13.320	13.869	-.549	-9.355	-9.229	-.126
12:10:55.2	80	12.560	12.936	-.376	-9.371	-9.229	-.142
12:10:59.1	81	11.950	12.183	-.233	-8.421	-9.053	.632
12:11: 3.0	82	11.350			-10.129		
12:11:10.9	84	10.430	11.435	-1.005	-9.588	-9.844	.256
12:11:18.7	86	9.670			-9.882		
12:11:26.6	88	8.970	9.929	-.959	-9.712	-10.195	.483
12:11:30.5	89	8.660			-9.987		
12:11:34.5	90	8.300	8.925	-.625	-9.904	-10.020	.116
12:11:38.4	91	7.970			-10.036		
12:11:42.3	92	7.720			-9.547		
12:11:50.2	94	7.150	7.476	-.326	-9.536	-9.756	.220
12:11:54.1	95	6.960	7.326	-.366	-9.459	-9.844	.385
12:11:58.0	96	6.670			-9.750		
12:12: 2.0	97	6.410			-8.333		
12:12: 5.9	98	6.210	6.771	-.561	-10.096	-10.020	-.076
12:12: 9.8	99	6.050			-9.492		
12:12:17.7	101	5.620	5.518	.102	-9.646	-9.053	-.593
12:12:21.6	102	5.450	5.372	.078	-9.695	-9.141	-.554
12:12:25.5	103	5.250	5.497	-.247	-9.196	-9.492	.296
12:12:37.3	106	4.780			-9.377		
12:12:41.2	107	4.720			-9.404		
12:12:53.0	110	4.360	3.057	1.303	-8.069	-8.877	.808
12:12:56.9	111	4.220			-9.344		
12:13: .9	112	4.170	4.114	.056	-9.168	-8.965	-.203
12:13: 4.8	113	4.080	4.161	-.081	-9.608	-9.229	-.379
12:13:12.8	115	3.930	4.178	-.248	-9.163	-9.492	.329
12:13:16.6	116	3.860	3.740	.120	-9.360	-8.877	-.483

DAZ MEAN: -.044 DAZ S.D.: .428 N= 56 SUM= -2.459 SUM OF SQUARES= 10.181

TBA MEAN: -.378 TBA S.D.: .415 N= 56 SUM= -21.140 SUM OF SQUARES= 17.452

-STOP- 0000000

TOA/DAZ ERROR ANALYSIS PROGRAM DATE . NO DATE . PAGE 0005

TARGET CODE: 0777 RUN 8,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TOA	ARTS TOA	TOA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:16:56.6	3	4.930			-9.794		
12:17: .5	4	5.120			-10.052		
12:17: 4.4	5	5.340			-10.228		
12:17: 9.3	6	5.530			-10.541		
12:17:16.2	8	5.890	5.708	.182	-10.168	-11.162	.994
12:17:20.1	9	6.160			-8.893		
12:17:24.1	10	6.430			-9.959		
12:17:31.9	12	7.030			-9.256		
12:17:35.8	13	7.420			-9.267		
12:17:39.8	14	7.970			-9.443		
12:17:47.6	16	9.220			-9.822		
12:17:55.5	18	10.760			-9.827		
12:17:59.4	19	11.680			-9.404		
12:18: 7.3	21	13.870			-10.003		
12:18:15.1	23	16.740			-9.597		
12:18:23.0	25	20.100	16.704	3.396	-10.047	-9.580	-.467
12:18:30.8	27	24.070	24.375	-.305	-10.129	-9.844	-.285
12:18:34.8	28	26.190			-9.833		
12:18:38.7	29	28.410	28.863	-.453	-10.360	-9.932	-.428
12:18:42.6	30	30.750	31.285	-.535	-10.096	-10.020	-.076
12:18:46.6	31	33.120	33.726	-.606	-9.937	-10.020	.083
12:18:50.4	32	35.600	36.026	-.426	-9.525	-9.668	.143
12:18:54.4	33	38.130	38.826	-.696	-9.849	-10.020	.171
12:19: 2.2	35	43.300	43.529	-.229	-9.871	-10.107	.236
12:19:10.1	37	48.640	49.217	-.577	-10.519	-10.547	.028
12:19:21.9	40	57.010	57.579	-.569	-9.871	-10.283	.412
12:19:25.8	41	59.860	60.641	-.781	-10.706	-10.811	.105
12:19:29.7	42	62.780			-10.344		
12:19:33.6	43	65.640			-11.497		
12:19:41.5	45	71.410			-12.057		
12:19:49.4	47	77.260	77.680	-.420	-11.448	-11.338	-.110
12:19:57.3	49	83.030	84.425	-1.395	-11.492	-11.250	-.242
12:20: 9.1	52	91.730	92.139	-.409	-12.634	-11.865	-.769
12:20:13.0	53	94.610	95.303	-.693	-11.816	-12.480	.664
12:20:17.0	54	97.490	98.409	-.919	-12.250	-12.656	.406

DAZ MEAN: .051 DAZ S.D.: .433 N= 17 SUM= .865 SUM OF SQUARES= 3.038

TOA MEAN: -.320 TOA S.D.: 1.012 N= 17 SUM= -5.435 SUM OF SQUARES= 18.117

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0006
TARGET CODE: 0777 RUN 9,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:28:28.0	21	98.690			1.159		
12:28:43.7	25	91.880			1.483		
12:28:47.6	26	90.070			1.307		
12:28:51.6	27	88.360			1.165		
12:28:55.5	28	86.590			1.236		
12:29: 3.4	30	83.150			2.181		
12:29: 7.3	31	81.340	81.667	-.327	1.802	1.406	.396
12:29:11.2	32	79.680	80.192	-.512	2.604	2.109	.495
12:29:15.2	33	78.090			3.549		
12:29:19.1	34	76.350			2.510		
12:29:23.0	35	74.600			2.450		
12:29:26.9	36	72.890	73.245	-.355	2.571	2.285	.286
12:29:30.9	37	71.160	71.728	-.568	2.598	2.637	-.039
12:29:34.8	38	69.450			2.565		
12:29:42.7	40	65.920	66.401	-.481	2.324	3.076	-.752
12:29:50.5	42	62.400			2.241		
12:29:54.4	43	60.660	61.003	-.343	2.016	2.197	-.181
12:30: 2.3	45	57.450			2.549		
12:30: 6.2	46	55.770			.692		
12:30:14.1	48	52.620	52.794	-.174	1.637	1.934	-.297
12:30:18.0	49	51.050	51.364	-.314	1.950	2.637	-.687
12:30:21.9	50	49.400	49.795	-.395	1.961	1.846	.115
12:30:25.9	51	47.730	44.940	2.790	1.780	2.373	-.593
12:30:29.8	52	46.080			2.164		
12:30:33.7	53	44.370	45.323	-.953	2.065	2.285	-.220
12:30:37.7	54	42.610			2.324		
12:30:41.6	55	40.920			2.516		
12:30:49.4	57	37.510			2.648		
12:30:53.4	58	35.940	36.705	-.765	2.812	2.988	-.176
12:31:13.0	63	28.220			3.351		
12:31:17.0	64	26.610			2.620		
12:31:20.9	65	25.080			3.087		
12:31:24.8	66	23.560			3.307		
12:31:36.6	69	19.200			2.648		
12:31:40.6	70	17.810			2.428		
12:31:48.5	72	15.180			2.549		
12:32: .3	75	11.790			2.670		
12:32: 4.2	76	10.720			3.203		
12:32:23.9	81	6.820			3.312		
12:32:27.8	82	6.320			3.433		
12:32:39.6	85	5.050			3.939		
12:32:47.5	87	4.300			2.620		
12:32:51.4	88	4.040			3.285		
12:32:55.4	89	3.870	4.118	-.248	2.741	2.812	-.071
12:33: 3.2	91	3.300			2.741		
12:33: 7.1	92	3.120			2.433		

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0007

TARGET CODE: 0777 RUN 9,LCAS 045,11/9/76,ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:33:15.0	94	2.760			3.186		
12:33:22.8	96	2.610	2.770	-.160	3.455	2.900	.555
12:33:26.8	97	2.410			3.433		
12:33:30.7	98	2.410			3.829		
12:33:34.6	99	2.220			3.439		
12:33:38.5	100	2.240	2.314	-.074	4.175	3.076	1.099
12:33:46.4	102	2.070	2.129	-.059	3.878	2.988	.890
12:33:46.4	102	2.610			3.834		
12:33:50.2	103	2.000	1.998	.002	4.037	2.900	1.137
12:34: 5.9	107	1.710	1.933	-.223	3.768	3.691	.077
12:34: 9.9	108	1.680			3.796		
12:34:13.8	109	1.560	1.642	-.082	3.593	3.076	.517
12:34:21.6	111	1.560	.434	1.126	4.065	3.340	.725
12:34:29.5	113	1.370			3.192		
12:34:33.4	114	1.360	1.473	-.113	3.356	3.340	.016

DAZ MEAN:	.157	DAZ S.D.:	.547	N= 21	SUM= 3.292	SUM OF SQUARES=	6.493
TBA MEAN:	-.106	TBA S.D.:	.772	N= 21	SUM= -2.228	SUM OF SQUARES=	12.162

TBA/DAZ ERROR ANALYSIS PROGRAM
TARGET CODE: 0777 RUN 10,LCAS 045,11/9/76,ASR4 DATE - NO DATE - PAGE 0008

TIME	SCAN NO.	BCAS TOA	ARTS TOA	TOA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:39:20.5	2	10.220			3.669		
12:39:24.5	3	11.710	12.348	-.638	3.082	3.604	-.522
12:39:28.4	4	13.340	13.972	-.632	2.642	3.164	-.522
12:39:32.3	5	15.290	9.379	5.911	2.922	3.076	-.154
12:39:40.2	7	19.740	19.916	-.176	3.642	2.988	.654
12:39:44.1	8	22.040	17.119	4.921	3.510	3.164	.346
12:39:48.1	9	24.500			3.686		
12:39:52.1	10	27.080	27.640	-.560	3.428	3.164	.264
12:39:59.9	12	32.380	33.221	-.841	3.516	3.516	.000
12:40: 7.8	14	37.890			3.252		
12:40:15.7	16	43.410			3.658		
12:40:19.8	17	48.250	48.942	-.692	3.115	3.691	-.576
12:40:27.4	19	51.940			2.994		
12:40:35.3	21	57.710			2.714		
12:40:39.3	22	60.690	58.153	2.537	2.840	3.604	-.764
12:40:43.2	23	63.550	64.037	-.487	2.637	2.812	-.175

DAZ MEAN:	-.145	DAZ S.D.:	.462	N= 10	SUM= -1.449	SUM OF SQUARES=	2.132
TOA MEAN:	.934	TOA S.D.:	2.570	N= 10	SUM= 9.343	SUM OF SQUARES=	68.167

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0010

TARGET CODE: 0777 RUN 11,LCAS 045,11/9/76 ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:52:34.6	67	17.950			5.510		
12:52:38.5	68	16.650	17.375	-.725	5.301	5.625	-.324
12:52:42.4	69	15.510	16.015	-.505	5.576	5.801	-.225
12:52:46.4	70	14.430			5.735		
12:52:50.3	71	13.400	14.065	-.665	5.768	5.625	.143
12:52:54.2	72	12.480			5.532		
12:52:58.2	73	11.660			5.735		
12:53: 2.1	74	10.810			5.636		
12:53: 6.0	75	10.070	11.205	-1.135	5.537	6.240	-.703
12:53: 9.9	76	9.460	9.786	-.326	5.471	5.625	-.154
12:53:13.9	77	8.840			5.466		
12:53:17.8	78	8.290	9.027	-.737	5.674	6.064	-.390
12:53:21.7	79	7.830	8.440	-.610	5.488	6.240	-.752
12:53:25.6	80	7.370	8.000	-.630	5.856	6.240	-.384
12:53:29.6	81	6.930	7.525	-.595	5.361	6.152	-.791
12:53:33.5	82	6.480	6.529	-.049	5.883	5.625	.258
12:53:37.4	83	6.140			6.048		
12:53:41.4	84	5.700	6.143	-.443	5.872	5.977	-.105
12:53:45.3	85	5.420	5.607	-.187	5.933	5.801	.132
12:53:49.2	86	5.120	5.414	-.294	5.669	5.889	-.220
12:53:53.1	87	4.860			5.883		
12:53:57.1	88	4.670	5.029	-.359	6.075	6.152	-.077
12:54: 1.0	89	4.400	4.944	-.544	5.856	6.328	-.472
12:54: 4.9	90	4.240	4.613	-.373	5.691	6.240	-.549
12:54:12.8	92	3.860			5.806		
12:54:16.7	93	3.700	4.122	-.422	5.999	6.328	-.329
12:54:24.6	95	3.480	3.846	-.366	5.883	6.240	-.357
12:54:28.5	96	3.430	3.669	-.239	5.977	6.240	-.263
12:54:32.5	97	3.260	3.467	-.207	5.691	6.064	-.373
12:54:36.4	98	3.210	3.713	-.503	5.867	6.768	-.901
12:54:40.3	99	3.090	3.179	-.089	5.680	5.977	-.297
12:54:44.3	100	3.040	2.966	.074	6.070	5.713	.357
12:54:48.2	101	2.840	3.050	-.210	5.883	6.064	-.181
12:54:52.1	102	2.870	3.103	-.233	5.938	6.416	-.478
12:55: .0	104	2.720	2.789	-.069	6.312	6.064	.248
12:55: 3.9	105	2.610	2.659	-.049	6.059	5.977	.082
12:55:11.8	107	2.490	2.398	.092	5.773	5.713	.060
12:55:15.7	108	2.410	2.390	.020	5.867	5.889	-.022
12:55:19.6	109	2.300	2.339	-.039	6.042	5.889	.153
12:55:23.6	110	2.270	2.254	.016	6.262	5.801	.461

DAZ MEAN:	-.209	DAZ S.D.:	.356	N=	69	SUM=	-14.433 SUM OF SQUARES=	11.656
TBA MEAN:	-.397	TBA S.D.:	.282	N=	69	SUM=	-27.416 SUM OF SQUARES=	16.303

TBA/DAZ ERROR ANALYSIS PROGRAM DATE • NO DATE • PAGE 0009
TARGET CODE: 0777 RUN 11,LCAS 045,11/9/76 ASR4

TIME	SCAN NO.	BCAS TBA	ARTS TBA	TBA DIFF	BCAS DAZ	ARTS DAZ	DAZ DIFF
----	----	----	----	----	----	----	----
12:49:33.8	21	93.310	93.586	-.276	4.417	4.482	-.065
12:49:37.7	22	91.620	92.039	-.419	4.625	4.834	-.209
12:49:41.6	23	89.900	90.461	-.561	5.059	4.658	.401
12:49:45.6	24	88.210	88.151	.059	5.570	5.098	.472
12:49:49.5	25	86.430	86.641	-.211	5.839	5.625	.214
12:49:53.4	26	84.710	85.081	-.371	5.394	5.537	-.143
12:49:57.3	27	82.970	83.533	-.563	5.806	5.537	.269
12:50: 1.3	28	81.240	81.207	.033	5.317	5.449	-.132
12:50: 5.2	29	79.450	79.691	-.241	5.334	6.152	-.818
12:50: 9.1	30	77.620	78.073	-.[illegible]3	5.186	5.449	-.263
12:50:13.1	31	75.830	76.569	-.739	5.098	5.713	-.615
12:50:17.0	32	74.040	74.229	-.189	5.444	5.361	.083
12:50:20.9	33	72.300	72.824	-.524	5.070	5.889	-.819
12:50:24.9	34	70.550	70.455	.095	5.147	5.273	-.126
12:50:28.8	35	68.870	68.996	-.126	4.993	5.713	-.720
12:50:32.7	36	67.150	67.402	-.252	5.317	5.186	.131
12:50:36.7	37	65.500	66.025	-.525	5.125	6.064	-.939
12:50:40.6	38	63.800	64.346	-.546	4.823	5.010	-.187
12:50:44.5	39	62.080	62.961	-.881	4.905	5.449	-.544
12:50:48.5	40	60.490	60.617	-.127	4.691	4.922	-.231
12:50:52.4	41	58.810	59.145	-.335	4.845	5.098	-.253
12:50:56.3	42	57.130	57.602	-.472	4.384	4.834	-.450
12:51: .3	43	55.450	56.050	-.600	4.510	4.834	-.324
12:51: 4.2	44	53.770	54.592	-.822	5.065	5.010	.055
12:51: 8.1	45	52.030	52.365	-.335	5.219	5.010	.209
12:51:12.1	46	50.280	50.810	-.530	4.774	4.922	-.148
12:51:16.0	47	48.540	49.456	-.916	5.186	5.449	-.263
12:51:19.9	48	46.890	47.331	-.441	5.663	5.713	-.050
12:51:23.9	49	45.210	45.716	-.506	5.416	5.098	.318
12:51:27.8	50	43.540	43.767	-.227	5.416	5.889	-.473
12:51:31.7	51	41.860	42.288	-.428	5.416	5.537	-.121
12:51:35.6	52	40.310			5.284		
12:51:39.6	53	38.690			5.609		
12:51:43.5	54	37.100			5.751		
12:51:47.4	55	35.450	36.320	-.870	5.609	6.504	-.895
12:51:51.4	56	33.830	34.805	-.975	5.620	6.152	-.532
12:51:55.3	57	32.230	32.707	-.477	5.762	6.152	-.390
12:51:59.2	58	30.640			5.773		
12:52: 3.2	59	29.100	30.010	-.910	5.916	6.064	-.148
12:52: 7.1	60	27.550	27.918	-.368	5.576	5.625	-.049
12:52:11.0	61	26.060			5.806		
12:52:15.0	62	24.680			5.806		
12:52:18.9	63	23.290	23.893	-.603	5.669	6.240	-.571
12:52:22.8	64	21.910	22.293	-.383	5.883	5.537	.346
12:52:26.7	65	20.570			6.070		
12:52:30.7	66	19.250			5.691		

APPENDIX G
ARTS III CONFIDENCE INTERVALS

The plots of slant range and bearing from the BCAS aircraft to the threat show the values of these quantities computed from the ARTS data bracketed by error bars which represent approximate 90% confidence intervals.

The confidence intervals were computed on the basis of calculations originally performed by K. Culbertson of Lockheed. In essence, the expressions for slant separation R_s and θ, the bearing of the target from the BCAS, in terms of the ARTS measurements R_1 and R_2 (the slant ranges to the two aircraft from the radar), ϕ_1 and ϕ_2 (the azimuth of the two aircraft), and H_1 and H_2 (their heights) were derived. These were

$$R_s\left(R_1, R_2, \phi_1, \phi_2, H_1, H_2\right)$$

and

$$\theta\left(R_1, R_2, \phi_1, \phi_2, H_1, H_2\right)$$

From these, the partial derivatives

$$\frac{\partial R_s}{\partial R_1}, \frac{\partial R_s}{\partial R_2} \text{ etc.}$$

were calculated.

To a first order approximation

$$\Delta R_s = R_s\left(R_1+\Delta R_1, R_2+\Delta R_2, \phi_1+\Delta\phi_1, \phi_2+\Delta\phi_2, H_1+\Delta H_1, H_2+\Delta H_2\right)$$

$$- R_s\left(R_1, R_2, \phi_1, \phi_2, H_1, H_2\right)$$

$$= \frac{\partial R_s}{\partial R_1}\Delta R_1 + \frac{\partial R_s}{\partial R_2}\Delta R_2 + \frac{\partial R_s}{\partial \phi_1}\Delta\phi_1 + \frac{\partial R_s}{\partial \phi_2}\Delta\phi_2$$

$$+ \frac{\partial R_s}{\partial H_1}\Delta H_1 + \frac{\partial R_s}{\partial H_2}\Delta H_2$$

If ΔR_1, ΔR_2 etc. are assumed to be measurement errors, the above is the expression for the error in the computed slant range separation due to ARTS measurement errors. The mean value of the measurement errors may be assumed to be zero, so that the mean value of the slant range error is also zero. The variance

$$\sigma^2_{R_s} = E\left[\left(\Delta R_s\right)^2\right]$$

or

$$\sigma^2_{R_s} = E\left[\left(\frac{\partial R_s}{\partial R_1}\Delta R_1 + \frac{\partial R_s}{\partial R_2}\Delta R_2 + \frac{\partial R_s}{\partial \phi_1}\Delta\phi_1 \right.\right.$$

$$\left.\left. + \frac{\partial R_s}{\partial \phi_2}\Delta\phi_2 + \frac{\partial R_s}{\partial H_1}\Delta H_1 + \frac{\partial R_s}{\partial H_2}\Delta H_2\right)^2\right]$$

The errors in the ARTS measurement of slant range and azimuth and the altitude errors are all intrinsically mutually independent. The errors in measuring the range and altitude of the two aircraft are in large part attributable to quantization errors in the radar range gates and the altimeter.

They are independent for the two aircraft. Culbertson has estabished, by comparing ARTS data with phototheodolite data for a pair of aircraft being tracked by both, that the azimuth errors for two aircraft also are independent. If all the different errors are assumed independent, then the above formula for $\sigma^2_{R_s}$ reduces to

$$\sigma^2_{R_s} = \left(\frac{\partial R_s}{\partial R_1}\right)^2 \sigma^2_{R_1} + \left(\frac{\partial R_s}{\partial R_2}\right)^2 \sigma^2_{R_2} + \left(\frac{\partial R_s}{\partial \phi_1}\right)^2 \sigma^2_{\phi_1} + \left(\frac{\partial R_s}{\partial \phi_2}\right)^2 \sigma^2_{\phi_2} + \left(\frac{\partial R_s}{\partial H_1}\right)^2 \sigma^2_{H_1} + \left(\frac{\partial R_s}{\partial H_2}\right)^2 \sigma^2_{H_2}$$

Since the measurement errors are statistically the same for both aircraft, this further reduces to

$$\sigma^2_{R_s} = \left[\left(\frac{\partial R_s}{\partial R_1}\right)^2 + \left(\frac{\partial R_s}{\partial R_2}\right)^2\right] \sigma^2_R + \left[\left(\frac{\partial R_s}{\partial \phi_1}\right)^2 + \left(\frac{\partial R_s}{\partial \phi_2}\right)^2\right] \sigma^2_\phi + \left[\left(\frac{\partial R_s}{\partial H_1}\right)^2 + \left(\frac{\partial R_s}{\partial H_2}\right)^2\right] \sigma^2_H$$

A similar expression holds for σ^2_θ. The values for σ_R, σ_ϕ and σ_H are

σ_R = .018 n.mi.

σ_ϕ = .25 degrees

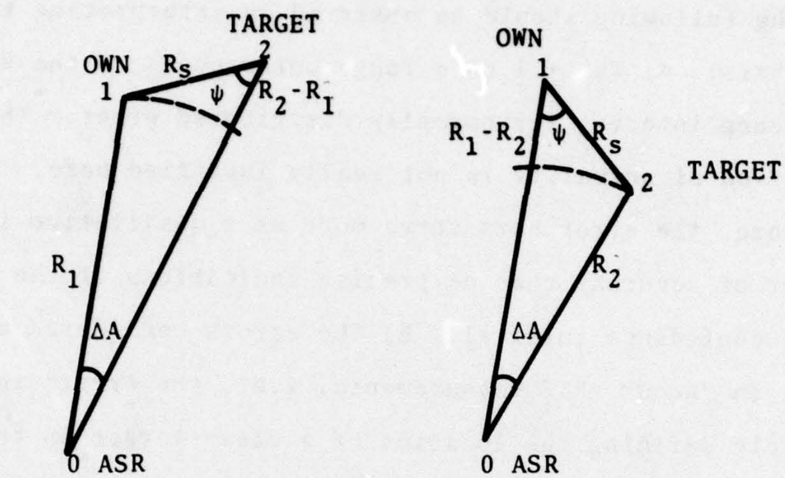
σ_H = 30 ft

Approximate expressions for $\sigma^2_{R_s}$ and σ^2_θ are shown in Figures G-1 and G-2.

In plotting the values R_s and θ obtained from the ARTS measurements, vertical lines were drawn about the computed values to show (approximately) the 90% confidence intervals for these values. These lines extend 1.65 σ above and below the computed value. Each such line is to be interpreted as the range within which the actual value of R_s or θ lies with a probability of 90%, given that the ARTS observations are the noise-corrupted value that were actually obtained.

It may be noted that the size of the confidence intervals is a function of the aircraft configurations. For instance, the confidence interval for θ is small when the aircraft are far apart and large when they are close together. This is readily explained. There is some uncertainty about the precise location of each aircraft. When the aircraft are far apart, relatively small displacements of either do not much change the direction toward the other. When the aircraft are close together, small displacements perpendicular to the line separating them can cause significant changes in bearing angle.

The following should be observed in interpreting the error bars: a) The $\pm$ 1.65 σ range corresponds to the 90% confidence interval for normally distributed error. The assumption of normality is not really justified here. Therefore, the error bars serve more as a qualitative indicator of accuracy than as precise indications of the size of the confidence interval. b) The errors considered are the errors in "good" ARTS measurements, i.e., the errors in precisely defining the location of a clear target in the absence of garble effects, "split target" errors, and other effects which cause either a wrong or an incomplete group of transponder replies to be identified as an ARTS target report. Such effects in general will cause wild points in the ARTS reply sequence. The probability that such wild points will occur and the magnitude of the resulting error have not been taken into account at all in constructing the error bars.



$R_2 > R_1$

$\cos\psi \simeq \frac{R_2 - R_1}{R_s}$

$R_2 < R_1$

$\cos\psi \simeq \frac{R_1 - R_2}{R_s}$

$$* \ \sigma^2_{R_s} \simeq \cos^2\psi \ (\sqrt{2}\sigma_R)^2 + \sin^2\psi \left\{ (R_M \sigma_{A12})^2 + \left(\frac{R_M}{R_m}\right) \sin^2 \frac{\Delta A}{2} \ (\sqrt{2}\ \sigma_R)^2 \right\}$$

where $\cos\psi \simeq |R_2 - R_1|/R_s$, $0° \leq \psi \leq 90°$

$R_M = \max\ (R_2, R_1)$, $R_m = \min\ (R_2, R_1)$

$\sigma^2_{A12} = 2(1 - \rho_{A12})\ \sigma^2_A$ = differential azimuth variance

σ^2_A = azimuth variance

σ^2_R = slant range variance

APPROXIMATION FORMULA FOR THE VARIANCE OF RANGE SEPARATION (R_s); $|\Delta A| \leq 18°$

FIGURE G-1: EXPRESSION FOR $\sigma^2_{R_s}$
[Source K. Culbertson]

MAX $(R_2,R_1) \geq$ NMI
AND $|R_2-R_1| \leq 5$ NMI

* $\sigma^2_{R_s} \simeq \cos^2\psi\,(\sqrt{2}\,\sigma_R)^2 + \sin^2\psi\,(R_M\sigma_{A12})^2$

* $\sigma^2_\theta \simeq \sigma^2_A + \frac{1}{R_s^2}\{\cos^2\psi\,(R_M\sigma_{A12})^2 + \sin^2\psi\,(\sqrt{2}\,\sigma_R)^2\}$

where $\cos\psi = |R_2-R_1|/R_s$, $|A_2-A_1| \leq 18°$

R_M = max (R_2,R_1)

σ^2_A = azimuth variance

$\sigma^2_{A12} = 2(1 - \rho_{A12})\,\sigma^2_A$

ρ_{A12} = correlation coefficient of A_2, A_1 errors (=0)

σ^2_R = slant range variance

<u>For $\psi = 0°$</u> (Radial Case: $A_2=A_1$, $R_2 \neq R_1$)

$$\sigma^2_{R_s} \simeq (\sqrt{2}\,\sigma_R)^2$$

$$\sigma^2_\theta \simeq \sigma^2_A + \frac{(R_M\sigma_{A12})^2}{R_s^2}$$

<u>For $\psi = 90°$</u> (Azimuth Case: $R_2=R_1$, $0° < |A_2-A_1| \leq 18°$)

$$\sigma^2_{R_s} \quad (R_M\sigma_{A12})^2$$

$$\sigma^2_\theta \simeq \sigma^2_A + \frac{(\sqrt{2}\sigma_R)^2}{R_s^2}$$

APPROXIMATION FORMULAS FOR VARIANCE OF RANGE SEPARATION (R_s) AND BEARING ANGLE (θ) WHEN MAX $(R_2,R_1) \geq 20$ NMI AND $|R_2-R_1| \leq 5$ NMI

FIGURE G-2. $\sigma^2_{R_s}$ AND σ^2_θ
[Source K. Culbertson]

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